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14. ABSTRACT
The DARPA Airborne Video Surveillance (AVS) program was established to develop and promote technologies to make airborne video more useful, providing capabilities that achieve a UAV force multiplier. Harris contributed to that goal with the develoment of processing solutions which permit precision video georegistration of streaming video data. The objective of this video georegistration technology develoment is to add operational value to video surveillance data by (1) automatically relating mission video imagery to precision controlled reference imagery to achieve metric-level targeting accuracy in near real time, and (2) producing video products and targeting readouts from streaming video data in support of time critical targeting and command and control tasks. Our PVR (Precision Video Registration) solution substantially alters the current mission model for video interpretation by creating timely, geospatially corrected tactical imagery ready for analysis and exploitation.

15. SUBJECT TERMS
Airborne Video Surveillance, Precision Video Registration, Mission Video Imagery, Precision Controlled Reference Imagery, Near Real Time Metric Level Targeting

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I. EXECUTIVE SUMMARY

The DARPA Airborne Video Surveillance (AVS) program was established to develop and promote technologies to make airborne video more useful, providing capabilities that achieve a UAV force multiplier. Harris contributed to that goal with the development of processing solutions which permit precision video georegistration of streaming video data. The objective of this video georegistration technology development is to add operational value to video surveillance data by (1) automatically relating mission video imagery to precision controlled reference imagery to achieve metric-level targeting accuracy in near real time, and (2) producing video products and targeting readouts from streaming video data in support of time critical targeting and command and control tasks. Our PVR (Precision Video Registration) solution substantially alters the current mission model for video interpretation by creating timely, geospatially corrected tactical imagery ready for analysis and exploitation.

In GFY'01, Harris was re-directed to stop customer-funded development work on its own processing capabilities, and tasked with validating the performance of both Harris and Sarnoff Precision Video Registration systems. Section II documents the results of that work. The Harris PVR registration performance results, relative to DOQ and DTED reference data, are summarized below in Figure 1.1. Section III provides a design overview of the Harris PVR system, and documents operational transition opportunities and associated technical issues. Our final activity summary may be found in Section IV.

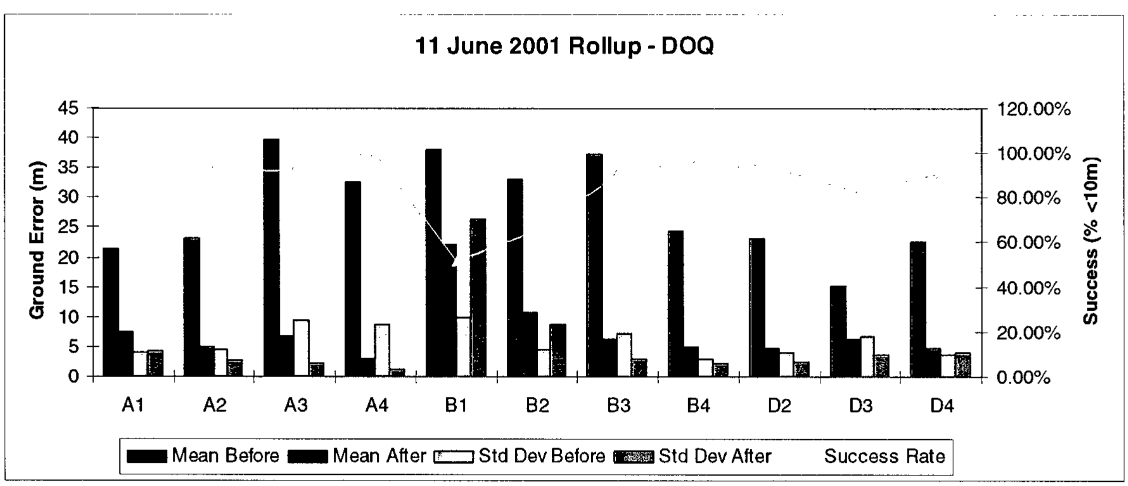


Figure 1.1: Harris EO Video to DOQ & DTED Registration Results

II. PRECISION VIDEO REGISTRATION VALIDATION

PVR Validation Protocol

In 1999 and 2000, the AVS program collected airborne video with embedded telemetry data over 4 CONUS sites using a DeHavilland DHC-6 Twin Otter testbed aircraft maintained and operated by the U.S. Army's Night Vision and Electronic Systems Directorate. The New York Site contains hilly terrain and had snow cover when the data was collected in February 2000. The North Carolina Site, a relatively flat littoral area with a mix of urban, suburban, and rural land use, was collected in March 2000. The desert valleys and rugged mountains of the Nevada Site were collected in May 2000. We also leveraged data collected in October 1999 over the gently rolling terrain of the Virginia Site's drop zone used for our live integrated AVS Flight Experiment. The goal was to evaluate PVR performance over a variety of operationally significant flight paths, look angles, ground sample distances, scene content qualities, seasonal variations, and terrain types. Towards that end, approximately 60 hours of EO and IR airborne video data was collected and distributed by the program team.

The mission video data distribution format for the AVS program is S-VHS video cassette tapes. The PVR TSRD (Technology Subsystem R&D) contractors are responsible for their own NTSC analog video capture hardware within their processing solutions. The associated metadata (a.k.a. exploitation support data (ESD) or telemetry data) is extracted from the VBI (vertical blanking interval) of the NTSC video signal by Norpak TTX745 data recovery hardware, and the resulting serial data stream is parsed into metadata packets by custom software according to the AVS Common Air / Ground System (CAGS) Interface Control Document (ICD) established at the program Critical Design Review in February 1999. Video rate is nominally 30Hz, and the metadata packets contain GPS vehicle position updates at a 10Hz rate, INS vehicle attitude updates at 30Hz, sensor gimbals pointing data at 25Hz, and sensor field of view updates at 6.25Hz.

PVR effectively transfers the higher accuracy of controlled reference imagery and elevation data (NIMA standard products) to more recent mission video collected by tactical airborne assets in order to derive precise locations of entities and events in support of intelligence, surveillance, and reconnaissance missions. USGS Digital Ortho Quarter Quad (DOQ) 1m GSD imagery was used by both TSRD contractors as an unclassified reference surrogate for the classified NIMA Controlled Image Base (CIB) product in order to facilitate algorithm development within their respective labs. FOUO NIMA Digital Terrain Elevation Data (DTED) is used in conjunction with DOQ or CIB reference imagery by the 3D processing algorithms of both PVR systems. Since classified Digital Point Positioning Data Base (DPPDB) stereo imagery is the only NIMA product certified for generation of precision targeting coordinates, we also employed this reference source in our validation exercise.

There are many factors that can influence the performance of video georegistration algorithms, generally falling into the 3 classes of image quality, terrain, and viewing geometry. Not all of the factors are independent, and the relationships and interactions between them are complex and nonlinear. The result is a large search space that could be explored to characterize the performance envelope of our PVR systems. Since a brute force attack on this problem was economically unfeasible and technically unjustifiable, we decided to focus on four primary factors: GSD (ground sample distance), look angle obliquity, scene content (i.e., the presence and distribution of distinctive pattern structure in the scene), and video-reference differences (e.g., season, weather, time of day, feature content and shape changes, sensor difference, etc.). The choice of these particular four factors was based on Harris' extensive experience in developing and evaluating state of the art georegistration capabilities for operational national and tactical systems.

Of the 60+ hours of available video, Table 2.1 shows the 17 video clips that were chosen by Harris for their internal PVR validation experiments. Each clip has been assigned a unique ID number, and is unambiguously specified by the site, mission tape ID, collection date, and VITC format (HHMMSSFF: hours, minutes, seconds, frame number) start and stop times. The validation protocol established by the AVS program team in April 2000 defines a "standard clip" that is 2 minutes in duration, sub-sampled at a 0.5Hz frame rate, and manually truthed using the MET™ Geopositioning Tool and Accuracy Assessment Tool. These two tools are supported by NIMA and used by them to generate targeting products and evaluate the accuracy of their sensors over time. The rationale for the standard clip definition is that it should be sufficiently long to capture an operationally significant imaging CONOPS, balanced against the labor involved in manually generating truth data for performance characterization. Having 60 truthed frames uniformly distributed throughout the 2 minute clip was deemed reasonable. The Frames column of Table 2.1 indicates the number of frames the human operator was actually able to mensurate out of the total number captured with approximately 2 seconds between them.

ID	Site	Tape	Date	VITC start	VITC stop	Frames	Name	Ref. Imagery	DTED
A1	NY	100d	23-Feb-00	16193907	16213907	60/61@2s	N. Wilna Zamboni	DPPDB,DOQ	L3, L1
A2	NY	100d	23-Feb-00	16440407	16460407	60/61@2s	Deferiet Zamboni	DPPDB,DOQ	L3, L1
[redacted]	NY	102d	23-Feb-00	20565000	21001600	61/104@2s	[redacted]	DPPDB,DOQ	L3, L1
A4	NY	102d	23-Feb-00	20340002	20360002	61/61@2s	Intersection Circle Stare	DPPDB,DOQ	L3, L1
[redacted]	NC	110d	29-Mar-00	14280002	14300002	57/61@2s	[redacted]	DPPDB,DOQ	L1, L1
B2	NC	106d	28-Mar-00	14342928	14363000	61/61@2s	Urban Zamboni	DPPDB,DOQ	L1, L1
B3	NC	113_	31-Mar-00	14123729	14143729	61/61@2s	Water Tank Circle Stare	DOQ	L1
B4	NC	108d	28-Mar-00	20131829	20154304	55/73@2s	Suburban Run (Sarnoff1)	DOQ	L1
C1	NV	117(F1)	8-May-00	17191417	17211415	60/61@2s	W. Gate Coarse Zamboni	DPPDB	L3
C2	NV	117(F1)	8-May-00	18200219	18220219	59/61@2s	W. Gate Moderate Zamboni	DPPDB	L3
C3	NV	122(F2)	11-May-00	19322429	19342429	57/61@2s	ZoomingCircleStare	DPPDB	L1
C4	NV	121(F2)	9-May-00	21425405	21445402	60/61@2s	Desert 0.5m GSD Run	DPPDB	L1
[redacted]	NV	121(F2)	9-May-00	20100602	20120606	61/61@2s	[redacted]	DPPDB	L1
D1	VA	90d	13-Oct-99	17573821	17593817	61/61@2s	13Oct99 Straight Line	DPPDB,DOQ	L3, L3
D2	VA	94d	15-Oct-99	18355529	18375928	61/63@2s	15Oct99 Fast Straight Line	DPPDB,DOQ	L3, L3
D3	VA	96d	16-Oct-99	17341201	17361402	62/62@2s	16Oct99 Straight Line	DPPDB,DOQ	L3, L3
D4	VA	98d	19-Oct-99	15135829	15155900	57/61@2s	19Oct99 Straight Line	DPPDB,DOQ	L3, L3

Legend
[redacted]
DOQ Validation Trials
Both Validation Trials

Table 2.1: Harris Mensurated Twin Otter EO Video Clips

The clip mensuration process involves the operator displaying each of the 60 video frames, orthorectified based on their raw telemetry data. The operator identifies a minimum of 6 salient points per video frame that are also readily identifiable in the reference imagery. The Geopositioning Tool is used to compute the ground point location (latitude, longitude, height) of an image point using the reference data (either DOQ and DTED, or a DPPDB stereo pair). This point is then transferred to the Accuracy Assessment Tool so that the operator can specify the corresponding image point in the video frame. The manually dropped points are used as truth data. The 3D Euclidian distance between the unregistered image points is measured, and the average for a frame is used to characterize its raw ESD error (also known as the initial alignment error).

The image coordinates (row, column) of the truth points were distributed to the TSRD contractors, along with the corresponding digitized video frames and raw ESD, so that their PVR algorithms could register the images and provide reported ground coordinates for the truth points. These reported ground coordinate locations for the same salient feature points were used to compute residual alignment error for the respective PVR systems in the same manner that initial alignment error was computed (averaging over all the truth points to arrive at a measurement for each frame). The Harris PVR system was able to process the 60 mensurated frames per "standard clip" to produce its results. The Sarnoff PVR system, which has a hardware front-end component, required provision of an additional 540 frames per clip, captured by the same digitizer, in order to process at a 5Hz frame rate.

PVR Performance Results

In this section we present PVR performance results for the 10 trials indicated by the legend of Table 2.1, 6 trials using DOQ imagery and DTED as reference data, and 4 trials using DPPDB as reference data. For each clip we have plotted initial ESD alignment error, as well as residual alignment error after processing by the Harris and Sarnoff Precision Video Registration systems.

DOQ & DTED Reference Data

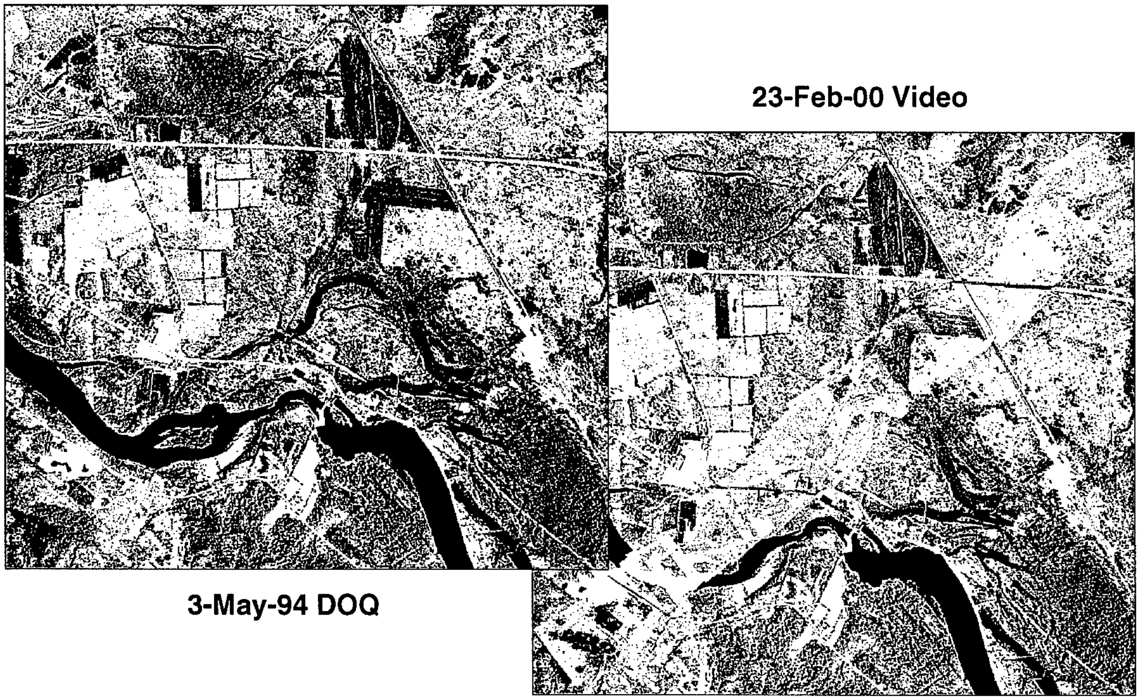
For our first 6 validation trials, we chose 2 clips from each of the collection sites for which we had unclassified DOQ reference imagery available (New York, North Carolina, and Virginia). For the Virginia Site, the AVS program was able to obtain DTED Level 3 (10m post spacing) elevation data, while only DTED Level 1 (100m post spacing) was available for the New York and North Carolina Sites. We show the reference imagery by itself in panel (a) of each of the clip summary figures (Figures 2.1 through 2.6), while panel (b) shows a mosaic of the video frames, with later frames on top of older frames, overlaying the reference DOQ image. Panel (c) plots the alignment errors for each mensurated frame in the clip, with clip performance summary statistics tabulated below (median, 90th percentile, mean, standard deviation, and percentage of frames meeting successful registration criterion of 10m or better residual alignment error).

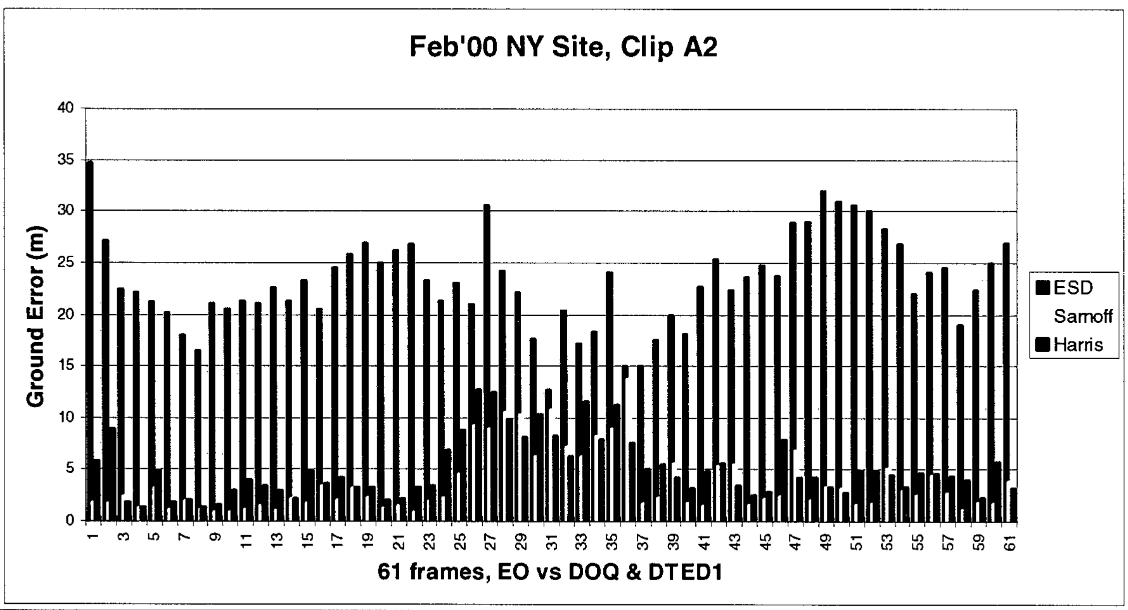
As shown in Figure 2.1, Clip A2 for the New York Site was collected with the sensor pointing down and directly ahead while flying a long linear run heading southwest across a river valley. The seasonal differences (ice covered river and snow covered ground) are clearly evident. For New York Clip A4, shown in Figure 2.2, the sensor stares at the intersection of two roads and a railroad as the aircraft circles it. In addition to the snow cover, note the large stand of trees northwest of the intersection that have been cleared between the mission and reference data collection times. Even with these video-reference differences, both PVR systems produced excellent results for the New York Site.

Circle stare and long linear run imaging CONOPS were also chosen for the North Carolina Site clips. Although the data formats and validation protocols were the same as they were for the New York site, the North Carolina Site proved to be problematic for the Sarnoff PVR system. They were unable to process Clip B3 at all, and so panel (c) in Figure 2.3 presents only the Harris PVR results plot and summary statistics. The "before" data series in that panel characterizes the initial ESD alignment error, the "kf" series is the residual alignment error, and "type" is a status line that indicates the state of the Harris Dynamic Video Worm algorithm, described in Section III of this Final Technical Report. Clip B4 of Figure 2.4 contains a long linear run flying south over varied scene content. In particular, note the cleared vs. built-up differences in the suburban development at the top (north end) of the run, challenging both PVR systems at the beginning of the clip.

The collections at the Virginia Site focused on the live processing vignettes for the integrated flight experiments and demonstrations held in the fall of 1999. Therefore, all PVR clips for this site focus on the same drop zone area, and are differentiated primarily by date. For Clip D2 of Figure 2.5, the aircraft flew a U-shaped pattern, with the first leg starting north of the drop zone and heading southeast. The depression angle of the sensor was 45°, with an azimuth angle of approximately 45° to the right of the aircraft heading. The sensor stared at the building compound at the southeast end of the drop zone as the aircraft did a clockwise turn about it, straightening out into the last northwestward leg of the U south of the drop zone with the sensor depression and azimuth angles both at 45° as before. The Sarnoff PVR system again had problems with this clip, dropping the last 10 frames and biasing their summary statistics presented in panel (c) of Figure 2.5. The sensor pointing angles for Clip D4 of Figure 2.6 were both held fixed at 45° as in D2, with the aircraft heading east while flying north of the drop zone, then turning southeast to scan its length. The poor scene content (mostly a dense forest of trees) at the beginning of the clip contributed to both PVR systems having a difficult time getting started.

A summary of both TSRD's EO video registration to DOQ & DTED reference data processing results is presented in Figure 2.7.

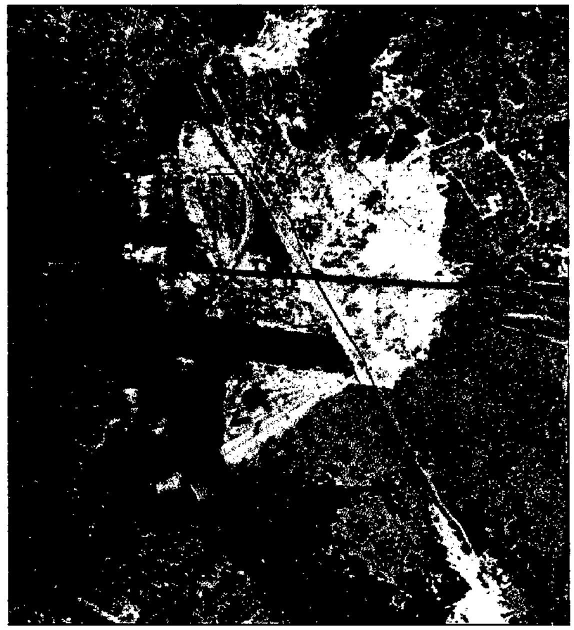




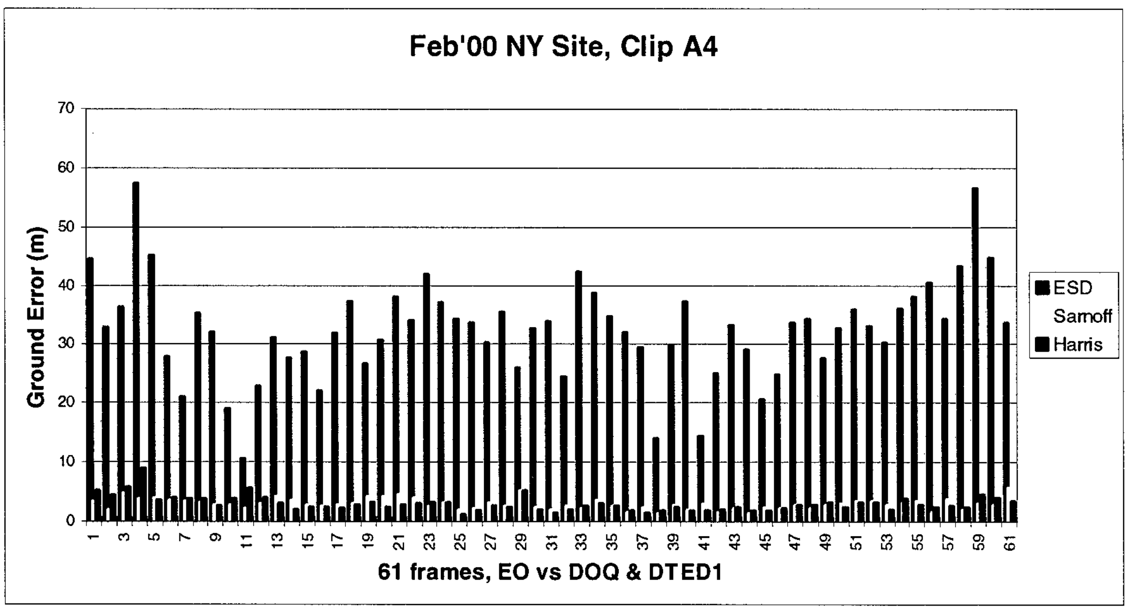
ESD	median:	22.7	90th:	29.0	mean:	23.2	std dev:	4.4	<10m:	0%
Harris	median:	4.2	90th:	8.9	mean:	5.0	std dev:	2.9	<10m:	92%
Sarnoff	median:	2.3	90th:	9.0	mean:	3.7	std dev:	3.0	<10m:	95%

Figure 2.1: NY-A2 Deferiet Zamboni Clip

3-May-94 DOQ

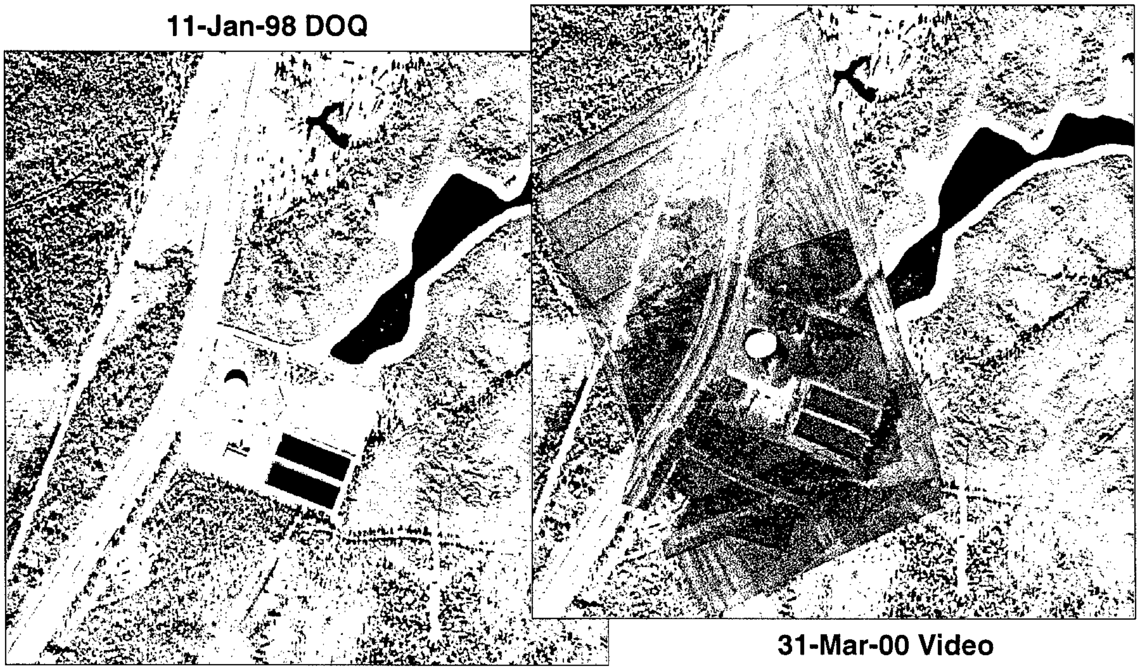


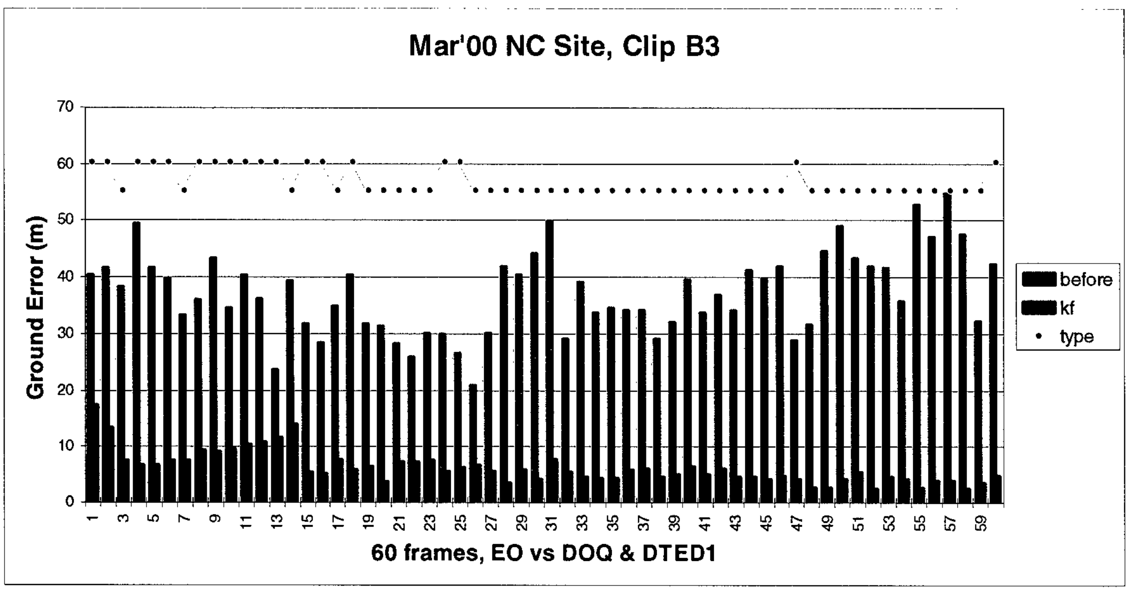
23-Feb-00 Video



ESD	median:	33.0	90th:	42.5		mean:	32.5		std dev:	8.7		<10m:	0%	
Harris	median:	2.7	90th:	4.4		mean:	3.0		std dev:	1.3		<10m:	100%	
Sarnoff	median:	2.8	90th:	4.1		mean:	2.9		std dev:	0.8		<10m:	100%	

Figure 2.2: NY-A4 Intersection Circle Stare Clip



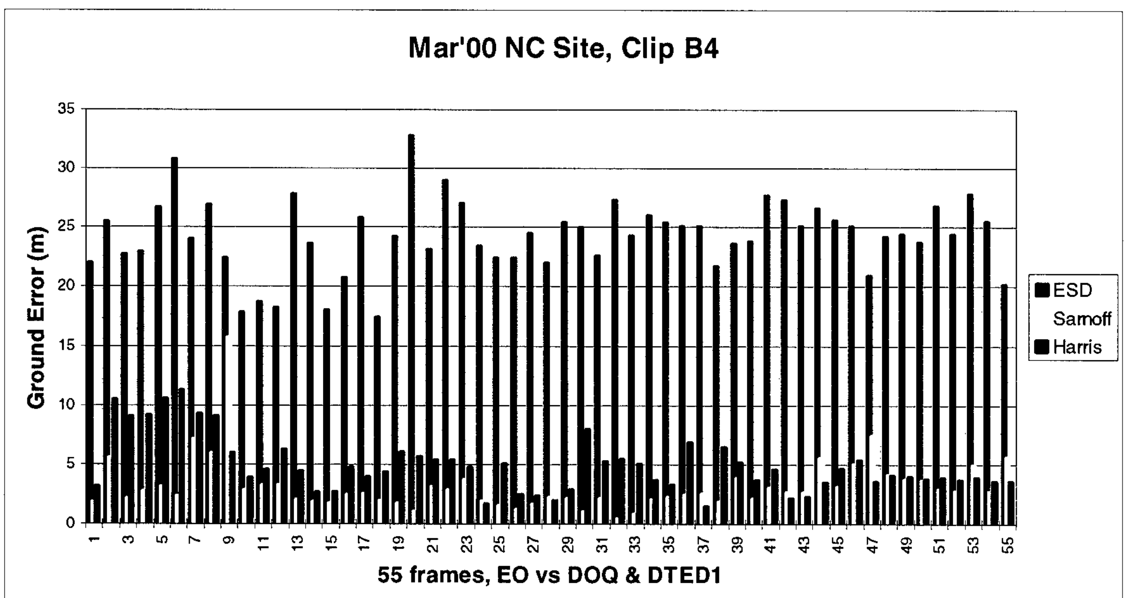


before:	median:	36.9	90th:	47.7	mean:	37.5	std dev:	7.6	<10m:	0%
kf:	median:	5.6	90th:	10.4	mean:	6.4	std dev:	3.2	<10m:	89%

Figure 2.3: NC-B3 Water Tank Circle Stare Clip

11-Jan-98 DOQ

28-Mar-00 Video

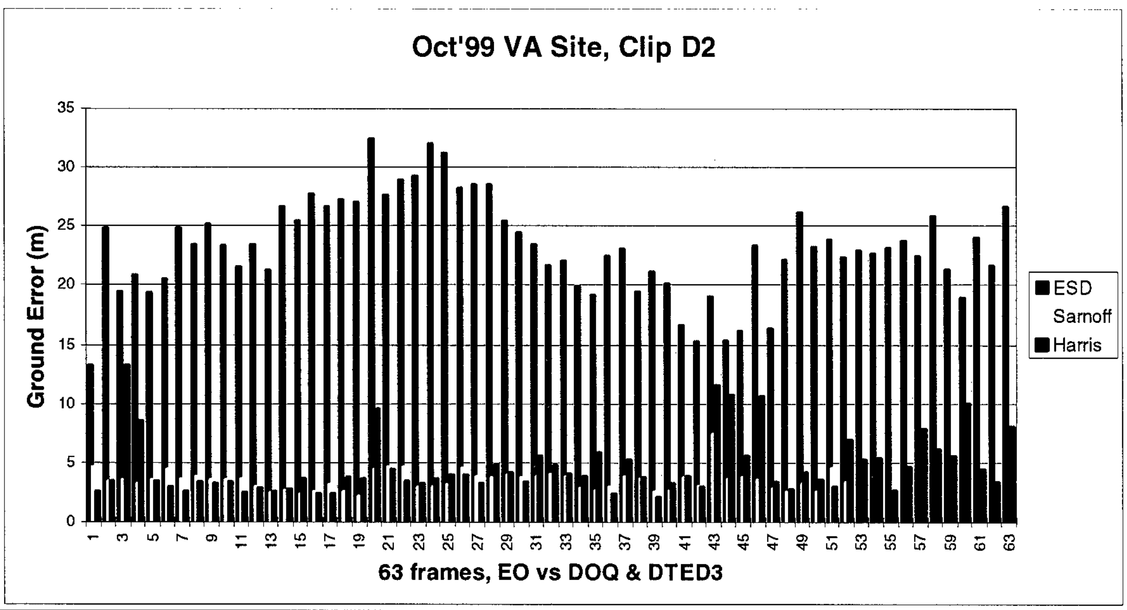


ESD	median:	24.4	90th:	27.6	mean:	24.3	std dev:	3.1	<10m:	0%
Harris	median:	4.5	90th:	9.1	mean:	4.9	std dev:	2.3	<10m:	96%
Sarnoff	median:	2.6	90th:	5.6	mean:	3.2	std dev:	2.3	<10m:	99%

Figure 2.4: NC-B4 Suburban Run Clip

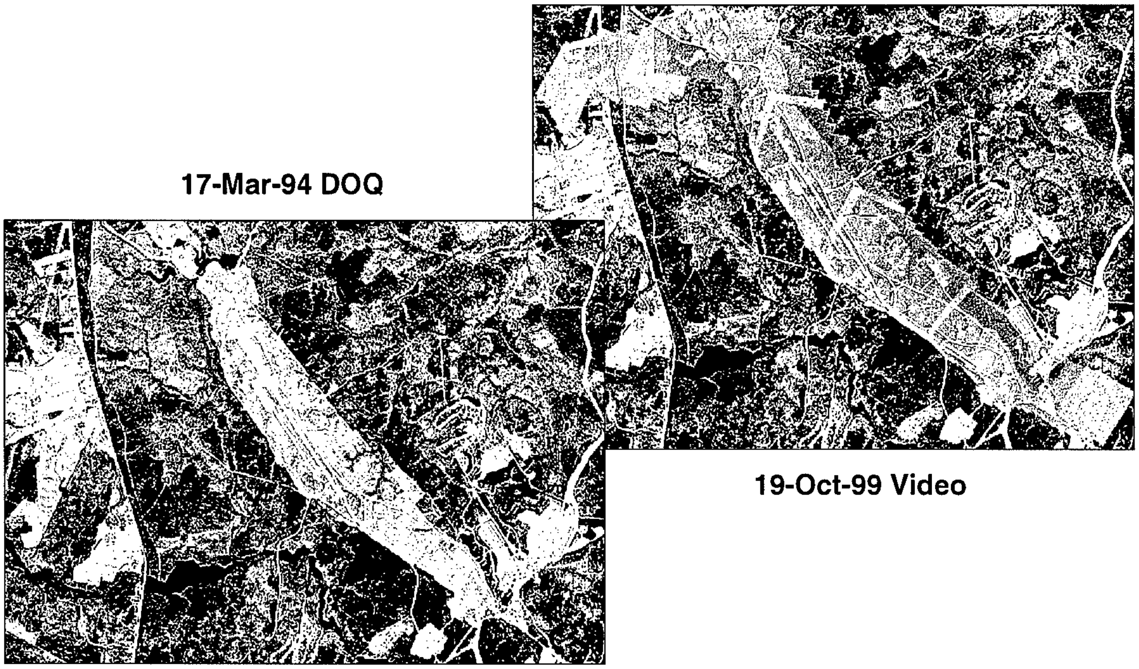
17-Mar-94 DOQ

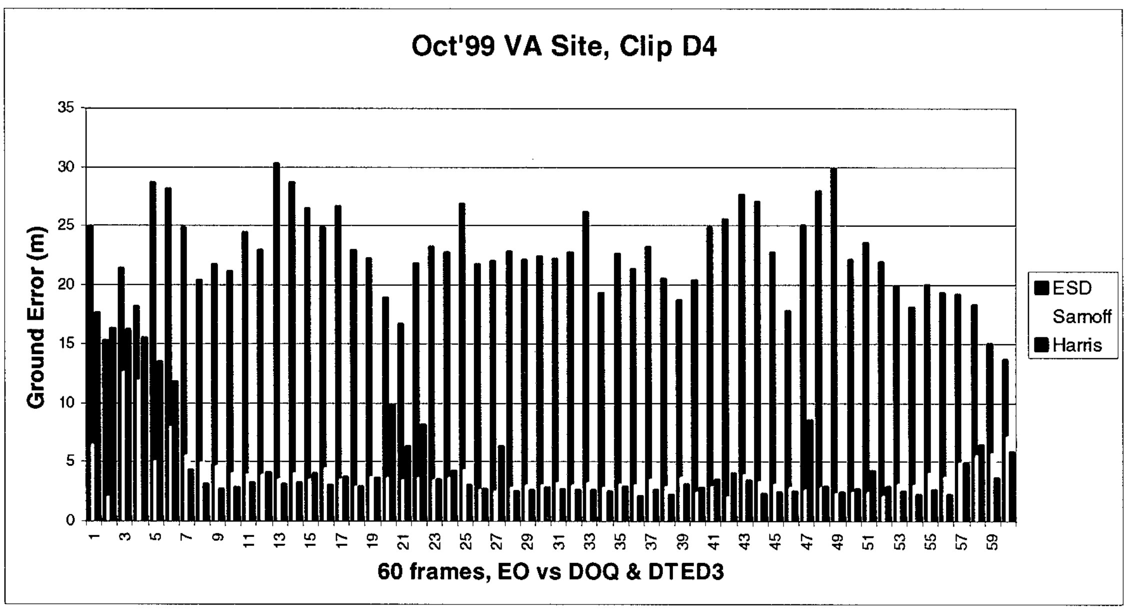
15-Oct-99 Video



ESD	median:	23.2	90th:	28.4	mean:	23.2	std dev:	4.1	<10m:	0%
Harris	median:	3.8	90th:	8.4	mean:	4.7	std dev:	2.5	<10m:	93%
Sarnoff	median:	3.6	90th:	4.6	mean:	3.5	std dev:	0.9	<10m:	100%

Figure 2.5: VA-D2 15-Oct Fast Straight Line Clip





ESD	median:	22.3	90th:	27.7	mean:	22.5	std dev:	3.7	<10m:	0%
Harris	median:	3.1	90th:	10.1	mean:	4.8	std dev:	3.9	<10m:	90%
Sarnoff	median:	3.5	90th:	5.6	mean:	3.9	std dev:	2.0	<10m:	97%

Figure 2.6: VA-D4 19-Oct Straight Line Clip

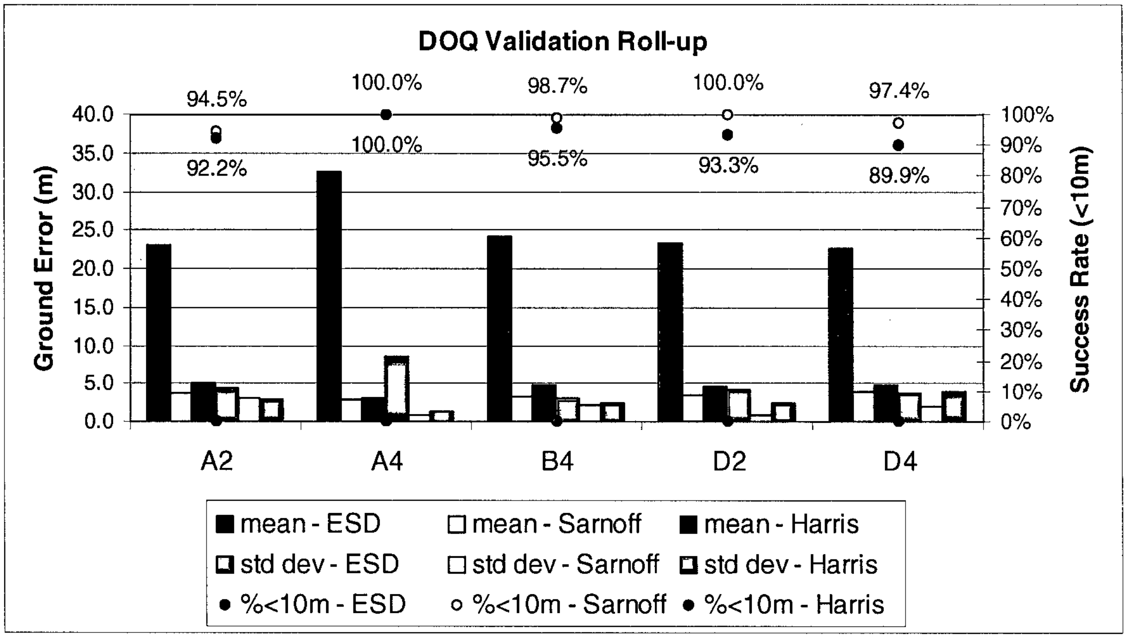


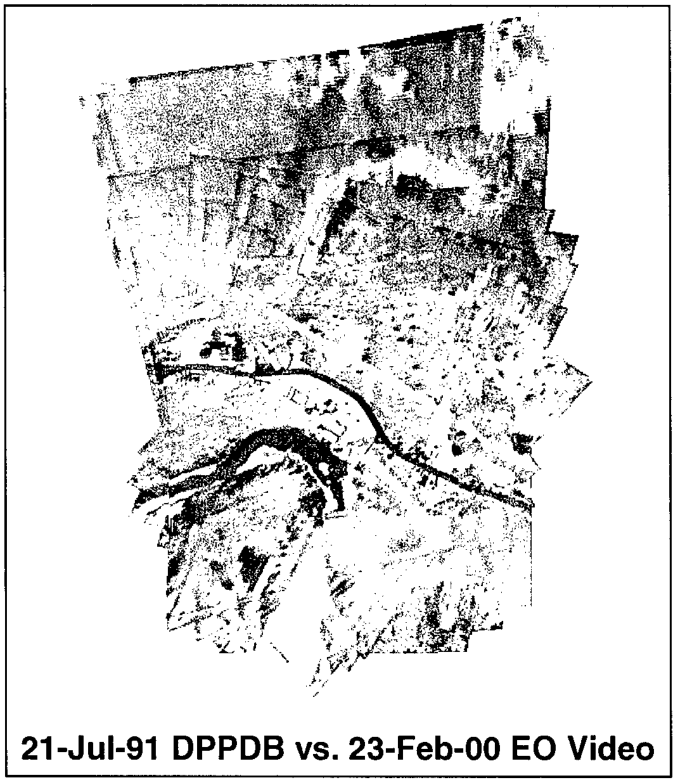
Figure 2.7: PVR System Validation for DOQ & DTED

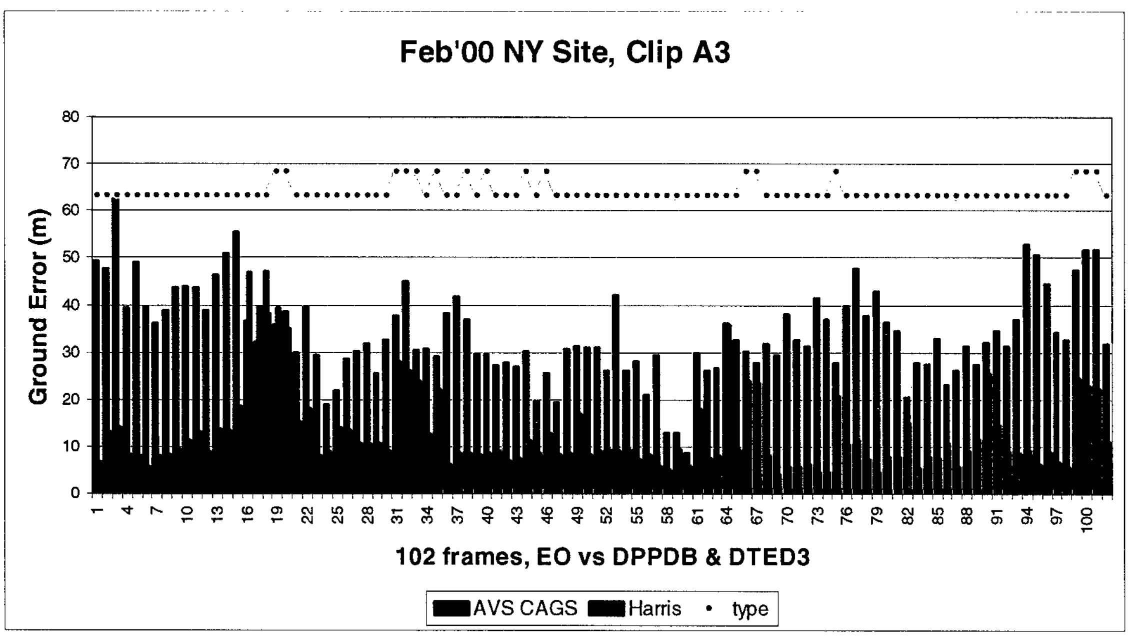
DPPDB Reference Data

For our last 4 validation trials, we chose one clip for each of the 4 collection sites to register against DPPDB stereo reference imagery. Because complete DOQ processing results were expected but never received from Sarnoff, they were never sent the selected DPPDB clips for processing. Since the reference imagery is classified, we show only the mosaicked video frames comprising the clips in panel (a) of Figures 2.8 through 2.11. Note, however, the large difference in collection times between the video and reference imagery documented in these figures, which proved to be a major factor in the Harris performance results presented in panel (b) of the figures.

Clip A3 from the New York Site is a circle stare about a large industrial chimney located at the center of the scene, as shown in Figure 2.8. The highly oblique sensor look angle, combined with the seasonal variation and significant age difference, made this a particularly challenging clip. The North Carolina Clip B1 comprised half of a U-shaped pattern (one leg and a turn), the first portion of which was exceedingly difficult because the causeway was torn down and replaced with a new one 170m to the west of its original location in the DPPDB imagery (moved from the easternmost north/south road in the video mosaic to the location shown in Figure 2.9). The Nevada Clip C5 is a long, linear run headed south with the sensor looking ahead with a 45° depression angle, as shown in Figure 2.10. The scene content was reasonable, consisting of desert arroyos, but was made difficult by high contrast shadows of high altitude clouds moving quickly across the scene. The final clip, D4 from the Virginia Site in Figure 2.11, is the same one used in the DOQ validation trials to provide a means of comparison between the reference types. A summary of Harris PVR registration to DPPDB is shown in Figure

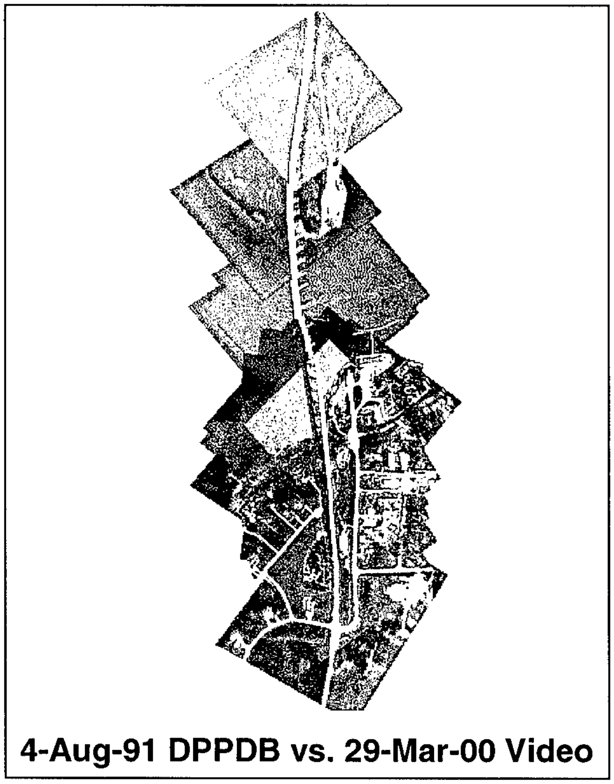
2.12.

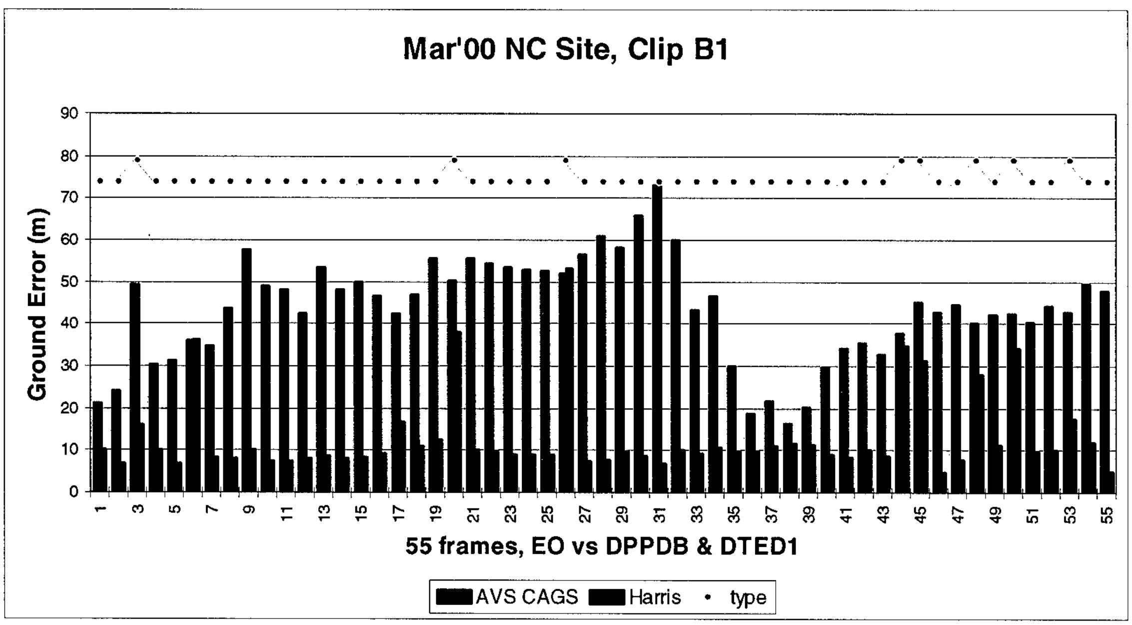




AVS CAGS:	**median:**	32.0	**90th:**	47.6	**mean:**	34.2	**std dev:**	9.6	**<10m:**	0%
Harris:	**median:**	9.2	**90th:**	24.1	**mean:**	12.7	**std dev:**	8.7	**<10m:**	58%

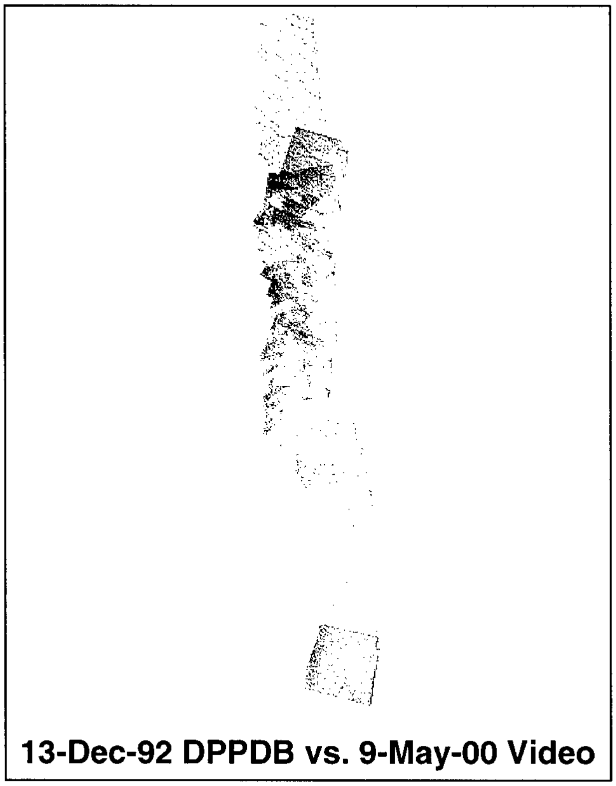
Figure 2.8: NY-A3 Chimney Circle Stare Clip

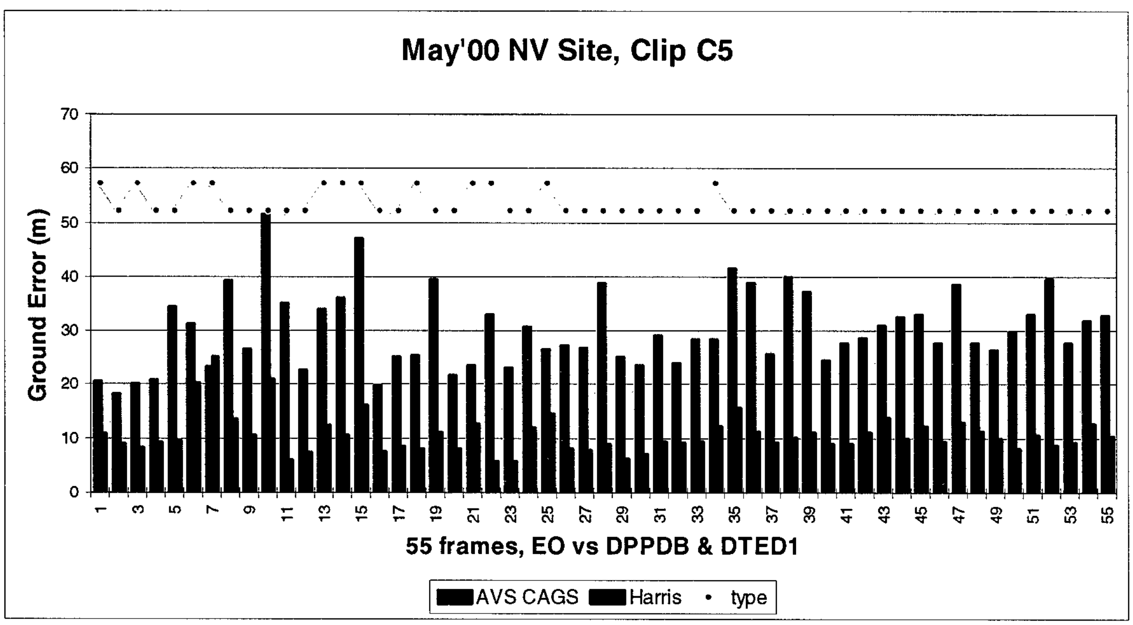




AVS CAGS:	**median:**	46.1	**90th:**	57.5	**mean:**	45.7	**std dev:**	10.4	**<10m:**	0%
Harris:	**median:**	10.0	**90th:**	39.0	**mean:**	14.0	**std dev:**	10.5	**<10m:**	51%

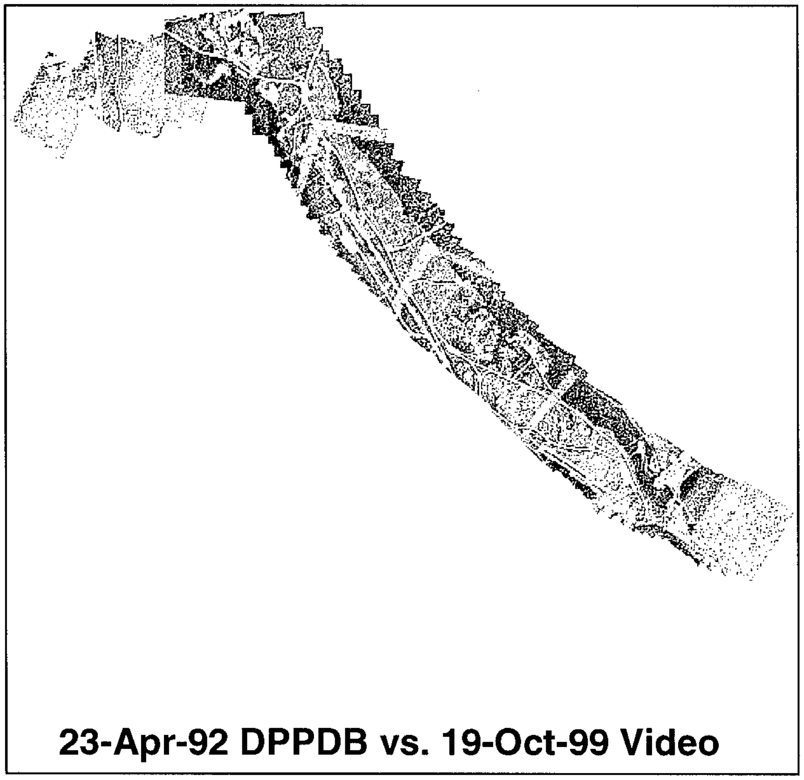
Figure 2.9: NC-B1 Causeway Circle Stare Clip

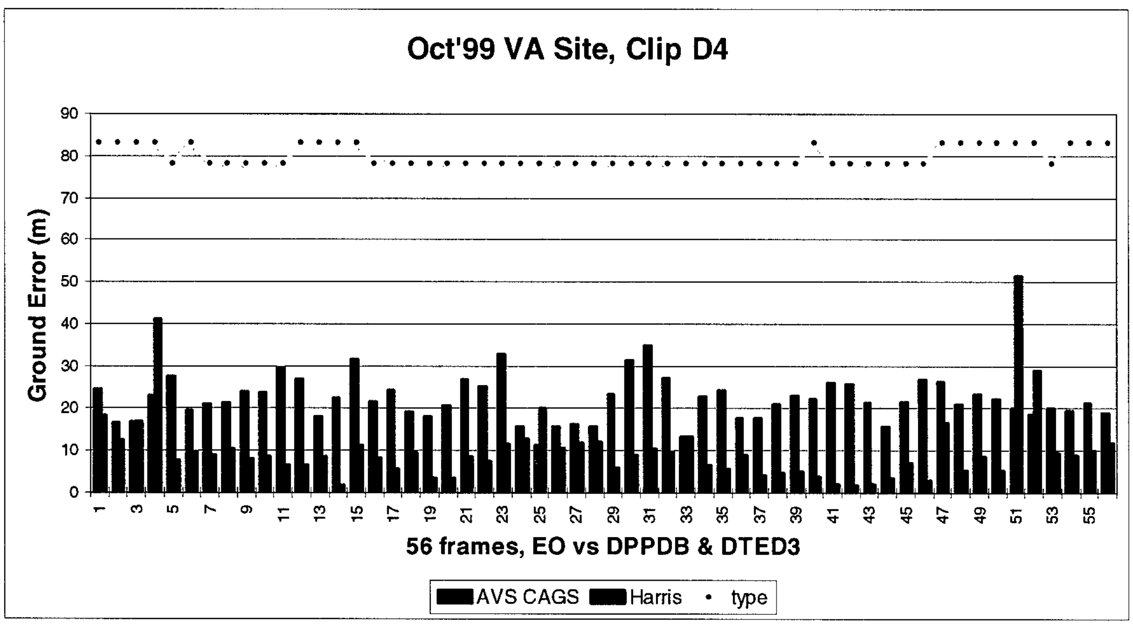




AVS CAGS:	**median:**	28.6	**90th:**	39.2	**mean:**	29.7	**std dev:**	7.9	**<10m:**	1%
Harris:	**median:**	10.0	**90th:**	24.2	**mean:**	10.6	**std dev:**	3.8	**<10m:**	49%

Figure 2.10: NV-C5 Desert 1.5m GSD Run Clip





AVS CAGS:	median:	21.7	90th:	27.5	mean:	22.1	std dev:	4.9	<10m:	0%
Harris:	median:	8.7	90th:	16.8	mean:	10.1	std dev:	8.6	<10m:	67%

Figure 2.11: VA-D4 19-Oct Straight Line Clip

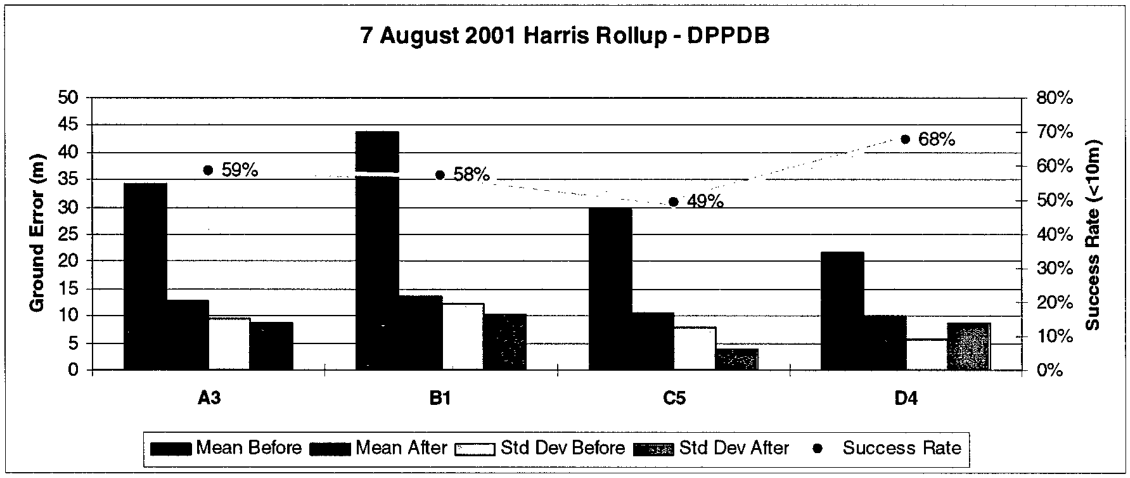


Figure 2.12: Harris Summary DPPDB Registration Performance

PVR Validation Conclusions

In general, the performance of both PVR systems met the AVS program goal of providing better than 10 meters CE registration accuracy, relative to the reference data, at a 1.0 Hz frame processing rate or better. Clearly, there is no significant accuracy difference in the performance of the validated versions of the two PVR systems we examined. Absolute error characterization was not possible due to the program's failure to collect and provide adequate site survey data required to perform that task (the NG-CMS provided data was examined and determined to be not suitable). Against DOQ and DTED reference data, the success rate was consistently greater than 90% using this criterion, with an overall mean of 3-5m of residual alignment error. Against DPPDB stereo reference imagery, Harris showed a success rate of 60%, with the mean relative residual alignment error at approximately the 10m success threshold due to the age of the reference and the difficulty of the data sets.

III. FINAL PVR DESIGN HIGHLIGHTS

At customer direction, there has been no DARPA-sponsored development of the Harris Precision Video Registration (PVR) system since the September 2000 AVS Program Management Review at Harris. This section provides highlights of the current Harris Precision Video Processing capabilities, which have been maintained, enhanced, extended, and ported to new platforms under Internal Research and Development funding. We also address operational transition opportunities and technical issues.

Harris PVR Design

The current Harris PVR system architecture, shown in Figure 3.1, is designed to accommodate the real-time flow of video images and telemetry support data into the four AVS PVR CSCIs (Computer Software Configuration Items). This architecture produces an asynchronous flow of improved telemetry to PVR subscribers and also supports ad hoc requests for georeferenced orthomosaics, precision geolocation results, and improved telemetry for specified video frames. The architecture utilizes multiple processes that share telemetry data via a dynamically updating database residing in shared memory. Processes within PVR communicate via PVM (Parallel Virtual Machine) messages. The PVR Services API wraps a CORBA interface to provide Precision Telemetry Broadcast packets and Mosaic Update imagery patches to the HCI, AM, and MTS within the SGI Infinite Reality hardware and AVS CAGS (Common Air / Ground System) software architectures.

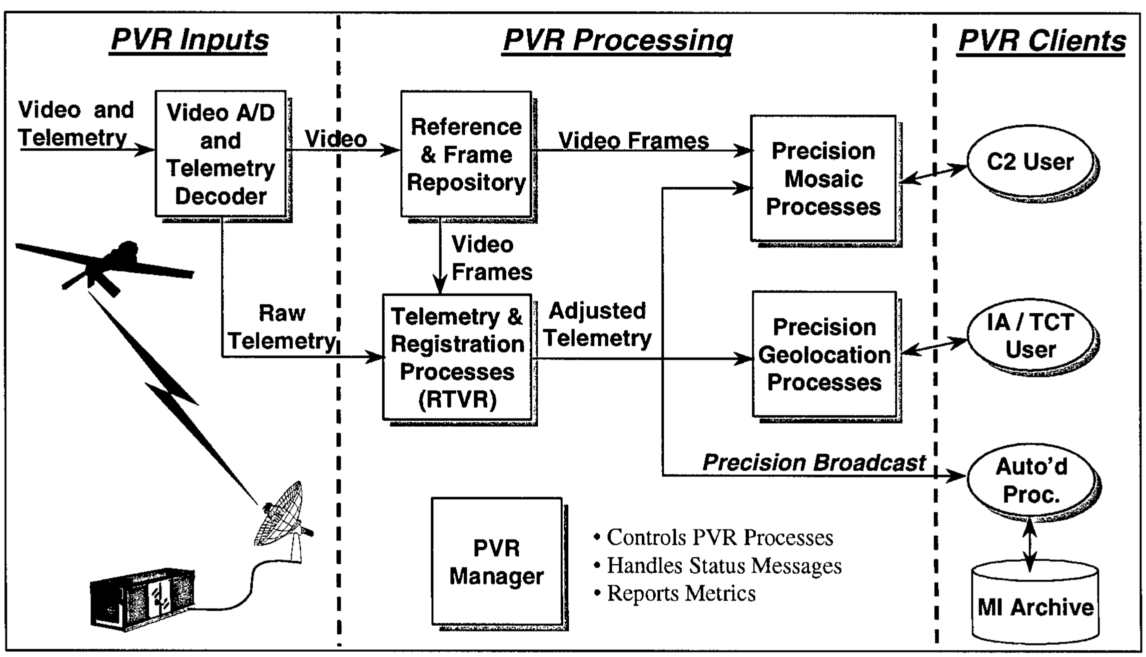
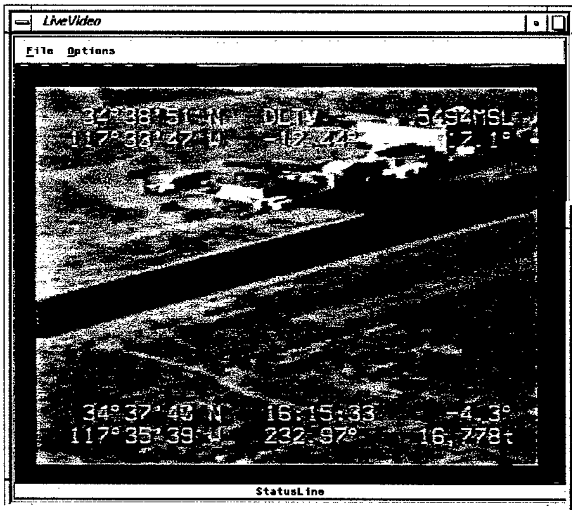
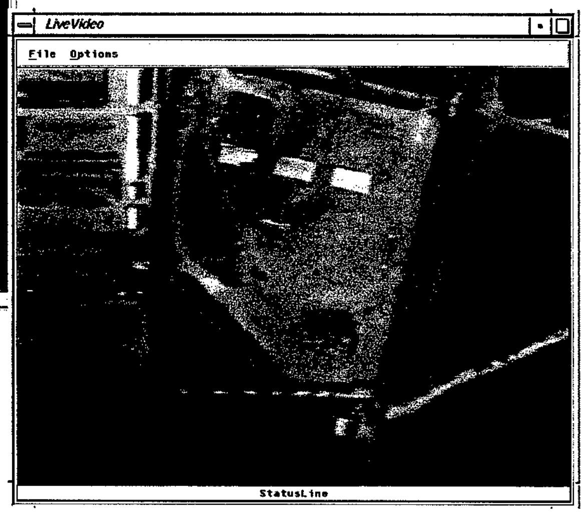


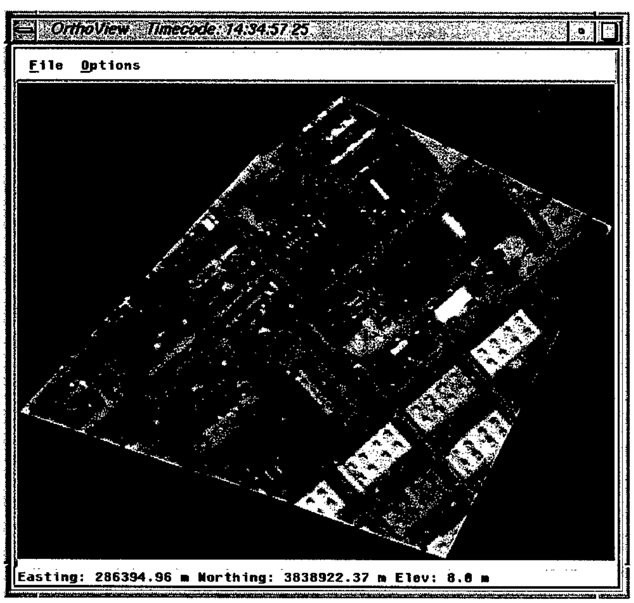
Figure 3.1: Harris PVR System Architecture





RQ-1 Predator UAV (above) and NVESD DHC-6 Twin Otter (right)

Figure 3.2: VET Live Video Displays



Time Critical Targeting (above) and C2 Situational Awareness (right)

Figure 3.3: VET Exploitation Displays

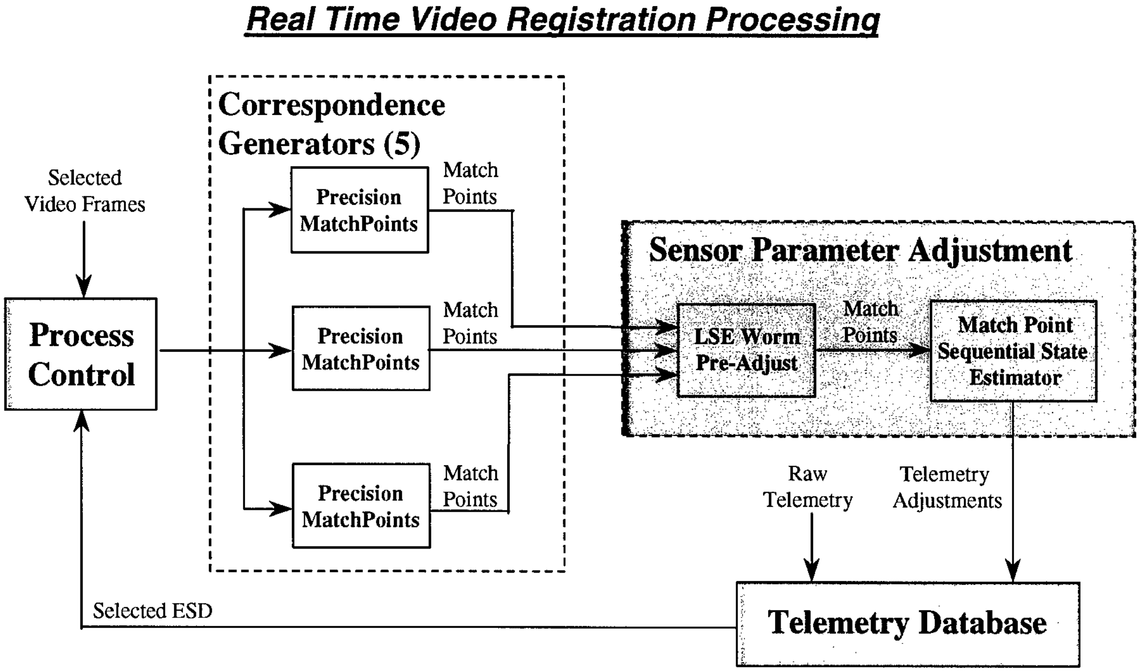


Figure 3.4: Real Time Video Registration (RTVR) Architecture

The live video, targeting, and situational awareness displays developed for the Harris Video Exploitation Toolkit (VET) COTS package (shown in Figures 3.2-3.3), and a Georegistered Video Database (GVDB) prototype of a motion imagery archive / GIS system are also licensable PVR client capabilities developed under Harris IR&D funding.

The Telemetry Processes CSCI of Figure 3.1 contains the RTVR kernel, the heart of the PVR technology. Figure 3.4 (Real Time Video Registration Architecture) illustrates the key components of the current design. Previous Quarterly Scientific and Technical Reports provided complete processing details for the GFY'99-GFY'00 versions of RTVR. Since that time, Harris has developed a proprietary Dynamic Video Worm registration algorithm that robustly accommodates varying scene content in narrow field of view airborne video imagery. A prototype version of this algorithm was validated in GFY'01 (see Section II for details) and presented at the first IEEE Workshop on Video Registration, held in conjunction with the Eighth IEEE International Conference on Computer Vision in July 2001.

RTVR registers incoming video image frames to reference imagery and provides near-real-time (NRT) adjustments to the telemetry stream, thereby providing improved accuracy for video users (HCI operators and/or embedded CAGS applications). Key features of the architecture include:

- Inputs:
  - Raw telemetry

- Video frames (IR or EO)
- Requests for telemetry at frame times with desired quality-of-service level
- Processing:
  - An autonomous frame selection process
  - Interpolation of metadata (due to various acquisition rates)
  - NRT multi-stage match point generation between incoming video frames and reference imagery
  - Prescreening of the match point sets to determine the success or failure of the current mission-to-reference frame registrations, which is used to control the set of frames participating in "video worm" and generation of frame-to-frame matches
  - A new least squares pre-adjustment of the bundle of frames comprising the "video worm", which are then fed sequentially into the Kalman filter adjustment stage
  - Adjustment of the telemetry stream via a Sequential State Estimator (Kalman filter which estimates the state of a system of measurements containing random errors)
- Outputs:
  - "Precision Broadcast" product - adjusted telemetry for automatically selected frames
  - "Telemetry Request" products; four levels of service to provide adjusted telemetry in response to ad hoc requests for specific frames
- Imaging Conops
  - PVR uses single sensor #1 (EO or IR) in wide to medium FOV. PVR registration performance is related to the accuracy and resolution of the reference imagery and terrain digital elevation model. Very narrow FOV operations may require high resolution reference imagery, and are automatically accommodated by the Dynamic Video Worm processing algorithm.
- Key Challenges
  - Large Engineering Support Data (ESD) errors with broad variances
  - Narrow Field of View (NFV) (scene content matching difficulty with small comparison patches)
  - Shallow sensor elevation angles
  - Sensor/video irregularities

At the August 2001 AVS Final Capabilities Demonstration, Harris showed the complete PVR System Architecture of Figure 3.1 performing real time end-to-end processing of S-VHS tapes of Twin Otter mission data collected for the PVR Validation task, just as it would perform live processing if integrated into the AVS CAGS as in the October 1999 Flight Experiment. Using an SGI Origin 3200, we demonstrated a 0.98 Hz frame registration rate with a 5.1 second latency. The PVR System software configuration consisted of the PVR Manager, 5 Mosaic Service processes, the RTVR Controller, 5

Correspondence Generators, and the Worm Combiner application. The Origin 3200 hardware configuration consisted of eight 400MHz R12000 CPU's with 8MB of cache per CPU, 4GB of RAM, and six 36GB JBOD (just a bunch of disks) with Fiber Channel I/O. An SGI O2 handled Video Capture, HMI Client Windows, and the Telemetry Ingest application.

PVR Technology Transition Opportunities and Issues

We also worked towards a GFY'01 AVS goal of demonstrating PVR technology on RQ-1 Predator data. Issues with the existing Predator ISR system include raw ground error on the order of hundreds of meters to several kilometers, unsynchronized video and metadata streams, and a very low 0.3 Hz metadata sampling and distribution rate. We obtained the Predator Metadata System ICD and developed ingest software compliant with that API. Modifications required to readily accommodate this format of metadata were made to our PVR system. We obtained an EEG Model DE241DR hardware data recovery decoder in order to process the current Predator data distribution format, and upgraded an existing Norpak Model TTX745 data recovery decoder's firmware in anticipation of a planned Predator Metadata System upgrade to achieve a higher 20 Hz metadata encoding rate.
We developed a rigorous and a simplified Predator sensor model, both of which are currently being calibrated with data collected in December 2001 (see Figure 3.5).

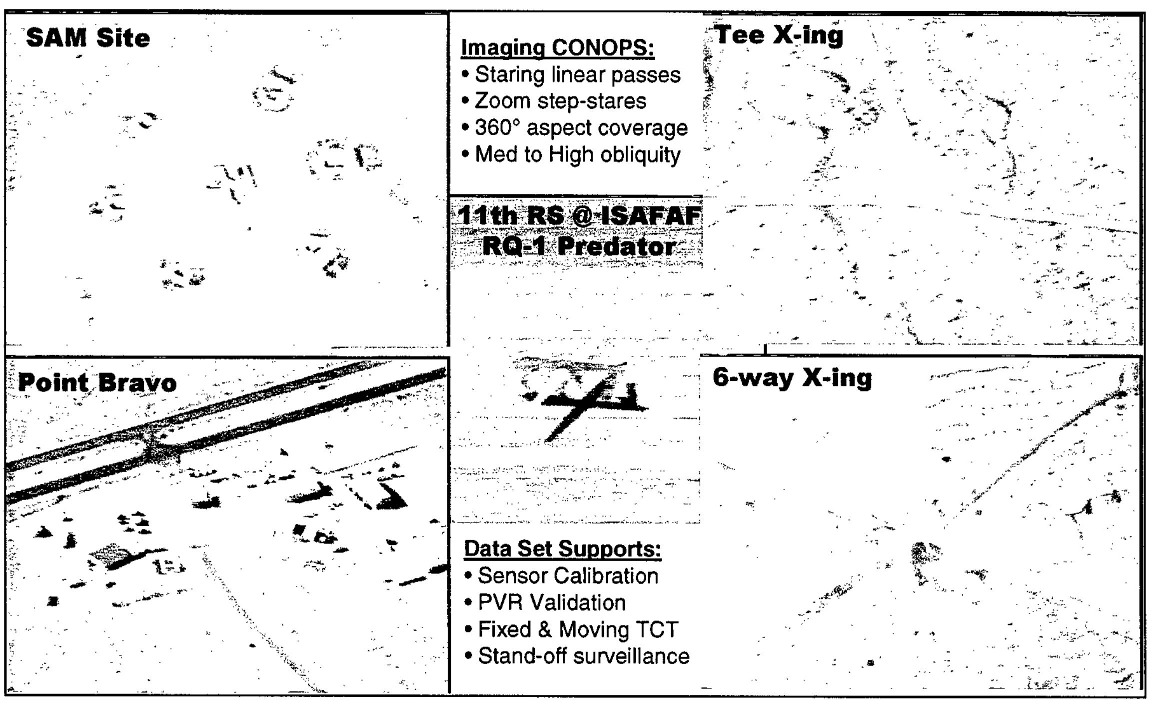


Figure 3.5: December 2001 Predator Data Collection

Harris has identified and pursued two follow-on opportunities with NIMA. In preparation for the NIMA-MIPO sponsored Motion Imagery Precision Engagement Program, we have been internally funding a port of our prototype PVR processing capability to the Harris ORIGIN COTS product software baseline to leverage a new, state-of-the-art registration processing architecture. This effort also facilitates hosting our new VET product under the Windows NT operating system, a requirement for delivering the capability to the NIMA motion imagery exploitation cells and the Predator Ground Control System (GCS). A manual bootstrap HMI has been designed to accommodate the large ground error and low distribution rate of the current Predator metadata stream. Harris has also identified and is pursuing a migration path that will quickly lead to compliance with the NIMA Motion Imagery Standard Board's requirements and recommendations for standard data formats and interfaces.

For the NIMA Tactical Smart Image ACTD, we will build on our existing PVR video-to-DPPDB registration capability by incorporating our fully autonomous solution to DEM extraction from stereo reference imagery. We will integrate a new replacement sensor model and error propagation formulation developed by NIMA to autonomously produce a new "smart image" product from streaming video that is suitable for precision target coordinate generation. We will deliver this capability to MIPO and the Predator GCS at Indian Springs, both of which require Windows NT and/or Windows 2000 support. In order to meet additional planned deliveries to CAOC-X and the DCGS sites, we must address security issues related to joint and coalition forces' centers of operation, as well as achieve DII COE Level 5 compliance. It is expected that NIMA will help fund these compliance issues, in addition to supporting certification of the geospatial accuracy of our motion imagery processing capabilities.

IV. FINAL ACTIVITY SUMMARY

Accomplishments for Quarter Ending July 31st 1998

R&D Trades:

- Completed first cut on the Sequential State Estimator (SSE)
- Identified the metadata inputs, system parameters, and level system calibration and characterization, necessary to the development of the sensor error model
- Developed video mosaic architecture and thread diagrams

PVR Design Development

- Created first draft of the PVR system architecture, threads and timing budgets
- Identified the CAGS Air Ground system partitions for the PVR
- Identified system interface requirements
- Identified 99 PVR-CAGS architecture performance criteria and timing budgets
- Identified 00 PVR-CAGS architecture performance criteria and timing budgets
- Identified PVR-CAGS computations and storage budgets
- Identified and assessed video storage and control COTS applications
- Identified PVR-CAGS MetaData types
- Developed a PVR Glossary of Terms and Acronym list
- Provided a Test Plan for 99 and 00 architectures
- Provided a staged Deliver Plan

Documentation

- Provided a Pre kickoff packages on the PVR design and scope
- Provided review and inputs for the June Data Collection Plan.
- Provided first draft of the HLDD/CONOPS before Kickoff
- Provided PVR system architecture, threads, and timing budgets and collaborated with SI on the CAGS environment
- Provided inputs for the August Data Collection Plan.

Workshops

- Presented the HLDD content at Kickoff at the AVS-SI [CMI] installation in Maryland.
- Supported the system architecture working groups at the kickoff
- Completed all Action Items assigned to Harris in Pre-Kickoff
- Completed of all Action Items assigned to Harris at the Kickoff
- Established Motion Imagery Group lab at Harris
- Arranged for HLDD review meeting with CMI at Harris on July 13-14th.

System Demonstration 98

- Developed first draft of the '98 Demonstration Plan and a schedule to provide demonstrations at Harris and support PDR "bazaar" in September.

Emerging Work

- Began the design audit of the Registration Architecture and considerations for prototyping
- Began the development of a CONOPS for Mosaics
- Began development trades for the Sequential State Estimator
- Began the assessment of the June Data Collection

Accomplishments for Quarter Ending November 30th 1998

R&D Trades:

- Prepared for utilizing the Twin Otter sensor by becoming more familiar with the Islander Video Image and Telemetry data set. The following are lessons learned from the Islander sensor suite imagery and telemetry:
  - We found the images to have significant smearing from mechanical modulations due to the location of the sensor
  - Attempted to get a good calibration run on ground objects.
  - The calibration runs have shown the need for good DTED (possibly Level 3).
- Definitized the draft criteria for frame selection
- Began taking statistics on Islander Telemetry to quantify the sub-packet rates necessary on the Twin Otter.
- Provided a CONOPS for Mosiacs paper
- Performed simulation experiments validating the utility of flow vector information within a sequential state estimator framework in order to improve registration performance.

PVR Design Development

- Created first draft of the PVR Software Design Document
- Created a draft PVR ICD
- Completed a '99 PVR Schedule for Design, Development, and Integration, and a staged delivery plan
- Updated the HLDD to include the PVR architecture and timelines
- Completed the AVS-PVR Preliminary Design Review
- Received a ROM from Earth Data to produce a 3" and 6" per pixel set of orthorectified reference images of the Ft. A.P. Hill area.
- Collaborated with CMI on the CAGS API development

Documentation

- Provided copies of the draft updates of the HLDD to CMI
- Provided a draft of the PVR API (ICD)

- Developed object-oriented design documentation within the Rational Rose tool in preparation for detailed design reviews of the PVR Manager, Image Control, and Telemetry process CPCI's.

Workshops

- Presented the PDR of the system architecture interfaces and technical performance measures and a Development and Integration Plan

System Demonstration 98

- Demonstrated the Harris registration of video images at the PDR and MSTAR Program Demonstration in September.

<u>Accomplishments for Quarter Ending February 28, 1999</u>

PVR Design Research and Development

- Prepared and presented to DARPA end-users at the AVS CONOPS Working Group
- Completed internal Registration Algorithm Design Review
- Completed coding & unit testing of the internal framework of multiple threaded processes
- Finished the detailed design and coding of initial versions of each CSCI (software component) of the PVR architecture
- Worked with TSRDs and CMI to develop a system level imaging CONOPS (Concept of Operations) to focus the system design through determination of how the sensors would be used in '99
- Collaborated with CMI on the CAGS API development
- Prepared and presented PVR architecture at the pre-CDR Software Working Group
- Completed the AVS Critical Design Review
- Completed two additional Technical Reviews with DARPA
- Developed & executed detailed experiments to characterize & assess the Islander data & RTVR design (ongoing – see "RTVR Development and Experimentation" below)
- Developed and began experimentation on a solution for a new requirement: PVR to generate flow vectors without MTS hardware inputs (ongoing – see "RTVR Development and Experimentation" below)
- Received VBI decoder hardware, software and test videotapes with VBI encoding, and began developing the software to extract Twin Otter VBI metadata
- Pursued and received partial information on Twin Otter sensor/gimbal/airframe metadata (detailed ICD-type information) and error characterization
- Collaborated with MTS to develop a joint MTS/PVR Vignette
- Coordinated NIMA and NVESD on acquisition of DTED level 2-3
- Pursued additional precision reference imagery for Ft. A.P. Hill via commercial sources.

Documentation

- Prepared the PVR Detailed Design Document
- Prepared the PVR Critical Design Review package
- Prepared two additional detailed technical briefings for DARPA
- Updated the CAGS API Document
- Updated the High Level Design Document (HLDD) to reflect the current design and alternatives being researched/developed
- Updated the Software Development Plan (SDP)
- Prepared the Mar. '99 Twin Otter Collection Plan
- Updated the PVR Software Design Document and object-oriented design documentation within the Rational Rose toolset

RTVR Development and Experimentation

- This was the focus of key research and technology efforts for the quarter. The February 1999 Quarterly Scientific & Technical Report contains detailed status.

Accomplishments for the Quarter Ending May 31, 1999

PVR Design Research and Development

- Completed two additional Technical Reviews with DARPA
- Performed Islander data experiments to validate both Sequential State Estimators (Match Point Generator SSE and Global Flow SSE) on real Islander video data
- Prototyped an implementation to incorporate scale and rotation effects into our match point consistent subset criterion and reduced the execution time of this algorithm
- Tracked results of affine/projective transform experiments on our Video IR&D (assessed potential leverage of this work for PVR match point generation).
- Completed experiments on a solution for a new requirement: PVR software-based generation of flow vectors without MTS hardware inputs
- Developed and tested a working metadata decoder and a video-ingest capability to extract Twin Otter VBI metadata and allow time-based look-up of video frames using VBI decoder hardware and videotapes with VBI encoding
- Pursued, received and incorporated into the design more information on Twin Otter sensor/gimbal/airframe metadata (detailed ICD-type information) and error characterization
- Selected and extracted video and telemetry clips from the March 99 Twin Otter data, characterized and plotted Otter ESD, found the data quality and telemetry is superior to Islander data
- Discovered significant scaling effects (3% to 39% error) due to incorrect linear mapping from zoom factor to FOV in CAGS metadata computations. Compensated

for this in the current data set, and designed/scheduled experiments to determine a complete calibration table for the program in the May data collection

- Gimbal azimuth and elevation angle errors were found to be an order of magnitude greater than the original spec, resulting in the addition of new adjustable parameters to our sensor model
- Conducted initial validation of RTVR design approach using the March Twin Otter data; pulled 202 frames of varying (best and worst) registration difficulty (depression angle and scene content) and achieved 99.5% success rate (accuracy improved), with 86% of the trials meeting the goal of $\leq$ 10 meter error.
- Analyzed timing issues associated with metadata delivery and frame-to-frame stabilization parameters, created a block diagram of the Twin Otter in the process.
- Demonstrated a "loose" end-to-end integration which proved we can ingest video and telemetry from our CAGS API emulators, and build a mosaic based on raw (uncorrected) telemetry in real time
- Evaluated different versions of SVHS tape dubs from the May 99 Twin Otter EO collection; the tape received from a NVESD dubbing consultant on 5/21 proved to have the smallest metadata dropout rate of 0.14 frames/second dropout rate (or 4.7 x 10^{-3} error rate), and image quality noticeably better than the original tape dub received on 5/12
- Developed a new level of "adjusted ESD" service that eliminates RTVR dependence on MTS Stabilization Parameters for user-specified frames
- Continued upgrade of our SGI O2's and our SGI Octane server to IRIX6.5.3 and the 7.2.1 compiler, and conducted integration/builds with the software
- Delivered 118 PTRs this quarter of new code and changes that arose out of our end-to-end integration of our CPCIs; all CPCIs except the RTVR kernel and PVR/CAGS integration classes were completed; the size of the AVS0.03 baseline at the end of the May period is 14477 LSS of new, 136000 LSS of reused/re-engineered code
- Continued Coordination with NIMA, DARPA and NVESD on acquisition of DTED level 2-3, helped obtain firm order for DTED 3 (projected delivery July 99)
- Continued to pursue additional precision reference imagery for Ft. A.P. Hill via NIMA and/or commercial sources

Documentation

- Prepared two additional detailed technical briefings for DARPA
- Updated the CAGS API Document
- Updated the High Level Design Document (HLDD) to reflect design changes
- Prepared the May '99 Twin Otter Collection Plan, and alternative plans to work around dual sensor collection difficulties
- Wrote and delivered the Quarterly Management Report (delivered 3/11)
- Wrote and delivered the Quarterly Scientific and Technical Report (delivered 3/17)
- Provided updates to the AVS Integration Milestones by Month document and schedule to CMI

RTVR Development and Experimentation

- This was the focus of key research and technology efforts for the quarter. The May 1999 Quarterly Scientific & Technical Report contains detailed status.

Accomplishments for the Quarter Ending September 30, 1999

PVR Development and Integration

June 1999:
- For the first time, demonstrated end-to-end Real Time Video Registration in the Harris lab running on multiple SGI O2's and an Octane. Multiple processes communicating via PVM ingested video and telemetry and registered streaming video frames as fast as possible and logged the results in a Telemetry Database for as long as we cared to run the system (10-15 minutes), with excellent results.
- Ported the AVS-PVR software baseline to IRIX6.5.3 and the 7.2.1 compiler to match the SIL development environment.
- Supported the June In-Process Working Group at Belcamp, MD.

July 1999:
- Supported an AVS Technical Review for the DARPA SPO director.
- Delivered PVR Release 1.0 compiled against the first available CAGS Ground Build that met the CDR spec (CORBA-free API). All PVR API interfaces are available for link testing in the SIL.
- DTED Level 3 reference data received and utilized in experiments characterizing RTVR processing results vs. DTED Level 1.

August 1999:
- Shipped PVR Release 2.0, which included the Affine Consistent Subset RTVR algorithm implementation with quantitative processing results for March PVR data.
- Supported the August In-Process Review at Ft. A. P. Hill.
- Shipped PVR Release 3.0, which consisted primarily of integration testing fixes and the Telemetry Rate implementation.

September 1999:
- Performed "reported field of view" to "adjusted focal length" calibration of the AVS EO sensor model based on new PVR data collected on 8/18 and 8/24. Implemented calibration of the AVS FLIR sensor model based on experimental measurements made by the Army Night Vision Lab in their Advanced Sensor Evaluation Facility.
- Implemented the Mono Match Point leg of the RTVR kernel to increase PVR robustness.

- Encountered metadata decoder hardware problems with the August and September PVR tapes, eventually traced cause to encoder gain changes within CAGS.
- Shipped PVR Release 4.0 on 9/22, began delivering patched versions of the PVR DSO library every other day via the ISDN connection to the SIL as integration problems were found and fixed. Continued to work video and telemetry ingest problems with the SI. SI begins HCI link testing against PVR API.

Accomplishments for the Quarter Ending December 31, 1999

PVR Development and Integration

October 1999:

- Shipped PVR Release 5.0 linked against final CAGS video & metadata ingest fixes.
- Internal PVR integration completed during on-site testing at Ft. A. P. Hill Oct. 5-8th.
- Delivered PVR Release 6.0, which included two significant PVR API interface changes to facilitate CAGS HCI integration, implementation of a scale change in our AVS sensor model to account for an unexpected CAGS video digitizer sampling rate, and modification of PVR service apps to save image and geometry files in order to overcome HCI deficiencies via use of the MET® tool.
- Supported on-site integration at Ft. A. P. Hill Oct. 13-18th, which included 3 live flight test experiments. Compiled preliminary RTVR processing results. CORBA distribution of PVR data had problems, and the threaded PVR mosaic processes would not run on the SGI Onyx2 Infinite Reality the way they ran in Harris lab. Built a more complete 1m GSD reference image of the demo area from USGS DOQ's.
- Successfully accomplished first major milestone of the AVS program by demonstrating a Live Flight Experiment at Ft. A. P. Hill on Oct. 19-20th to DARPA and their invited guests.

November 1999:

- Continued RTVR performance analysis and tuning activities, including experiment-driven fixes to the kernel.
- Conducted in-house post-demonstration assessment of PVR performance using approved MOEs.
- Supported DARPA-AVS promotional video shoot, built a new mosaic demo clip.
- Performed more extensive analysis of the effects of the reference DEM on RTVR performance (DTED Level 1 vs. USGS DEM vs. DTED Level 3).
- Documented PVR for GFY'99 in this Quarterly Scientific and Technical Report.

December 1999:

- Finished calibration of 15 October data collect, began calibration of 13, 16, and 19 October data collects to finish out GFY'99 performance analysis.
- Began port of AVS2x baseline to IRIX6.5 in order to completely synchronize the Harris software development environment with the GFY'00 SIL.

- Supported ECP response to the GFY'00 RFP based on program redirection by DARPA management.

Accomplishments for the Quarter Ending March 31, 2000

PVR Development and Integration

The main thrust of this past quarter was in developing detailed plans for our PVR experimental evaluation and technology development activities for GFY'00. However, extensive experimentation was done in the Harris Lab to continue making progress. We documented our October 8th, 15th, 13th, 16th, and 19th processing results for Ft. A.P. Hill data. We also described our N-View algorithm experiments and results, Mono Match Point utility experiments and results, and plans for experimentally evaluating our SSE and finalizing the state vector model it employs.

January 2000:

- Continued calibration, processing, and analysis of all October '99 PVR data collects.
- Developed GFY'00 Technology Development Plan in response to CECOM and DARPA request for program re-planning based on DARPA revision to the technical management strategy for the AVS program.
- Obtained Predator metadata specs and video data from Sarnoff.
- Obtained and reviewed DPPDB performance specs and product classification guide.
- Continued port of PVR software baseline to IRIX6.5.
- Prepared and delivered 5th Quarterly Scientific and Technical Report CDRL.

February 2000:

- Submitted the Harris AVS RFP response.
- Completed initial N-View algorithm experiments, planned SSE evaluation.
- Received DPPDB reference imagery for the GFY'00 collection sites from the govt., awaiting DD Form 254 authorization to process the data.
- Helped govt. procure DOQ reference imagery for Ft. Drum. Planned data collection flights, provided on-site support at Ft. Drum Feb. 22-25th.
- Calibrated hundreds of October '99 video frames, continued performance analysis.
- Completed port of PVR baseline to IRIX6.5.

March 2000:

- Submitted two clarifications and modifications responses to DARPA and CECOM.
- Submitted a detailed GFY'00 Experiment Plan documenting our data collection requirements and capability development schedule. Generated an AVS Data Management Plan describing the organization of AVS data and archival scheme for PVR experiment and evaluation processing results. Supported program-wide telecons and started a draft GFY'00 Evaluation Plan documenting how PVR performance should be measured and reported.
- Completed Mono Match Point algorithm experiments.

- Planned Camp Lejeune data collection flights for the week of 3/27/00. Received Harris copies of the Ft. Drum video data on 3/30/00. Received new Predator video data from NIMA (collected Sept. '99). Received DD Form 254 authorization for DPPDB late in the month and AVS personnel were briefed on lab security procedures, so we are set up to process DPPDB imagery starting in April.
- PVR7.0 pro-forma external release ready for delivery on schedule, but shipment delayed until the proper compiler version is available in the SIL for on-site integration and testing.

Accomplishments for the Quarter Ending June 30, 2000

PVR Development and Integration

The main thrust of this past quarter was in developing new DPPDB stereo registration capabilities, continuing to refine our registration algorithms, and rapidly producing performance results against the latest GFY'00 data sets. The team has been challenged by the late start this GFY, which resulted in a delayed staffing ramp-up, and the delays in getting the necessary equipment for our classified processing. However, extensive experimentation was done in the unclassified Harris Lab to continue making progress. Considerable effort was also expended on establishing a PVR Metrics-Based Evaluation Plan and Predictive Performance Model, which is documented in a detailed briefing to be presented next quarter.

April 2000:

- Hosted on-site working meeting with DARPA PM and SI to discuss program-wide Video Georegistration Evaluation Process issues on 4/11/2000.
- Visited NG-CMS on 4/26 to brief them and Sarnoff on the Harris PVR video processing tools. Demonstrated the use of MET® to drop calibration points, discussed other PVR applications which then measure, plot, and roll up statistics for registration performance characterization. The program appears to be converging on the Harris tools and methodology, but no firm commitment has been made by the SI. Followed direction of DARPA PM to focus on experimental characterization of PVR performance within our lab using all available data.
- Completed Mono Match Point experiments, as planned. Continued to evaluate and refine our Real Time Video Registration approach. SSE (Kalman filter) experiments are under way.
- Delivered PVR Release 7.0 to NG-CMS, continuing to make our internal tools available to the program for external evaluation purposes.
- Re-organized and documented our data management scheme to prepare for the onslaught of video we have to process this GFY. Received Ft. Drum and Camp Lejeune data, planned Fallon NAS collect. Installed DewDrop (GOTS DPPDB viewer) in the classified TSL facility, ordered stereo display hardware. Began processing Ft. Drum data in the unclassified AVS lab.
- Prepared and delivered 6-7th Quarterly Scientific and Technical Report CDRLs.

- Obtained a Department of Commerce export control license waiver for the MET/PVR software on 4/26 in order to facilitate collaboration with the University of Central Florida. Still awaiting DARPA written approval to release AVS data to UCF.

May 2000:

- Brought on another SW engineer to help the team quickly build visualization tools and scripts to facilitate data set QA, telemetry analysis, reference imagery determination, video clip selection, and capture of frame sequences to support experiments and performance evaluations.
- Ran telemetry database analysis tool on Oct. '99 Ft. A.P. Hill data sets, diagnosed metadata decoding HW sensitivity to choice of VTR, use of GFE VTR obtained last month fixes the associated problems. Began validation of Ft. Drum and Camp LeJeune data sets. Selected, ordered, and received reference DOQ's for Ft. Drum and Camp LeJeune. Began selecting, pulling, and processing video clips.
- Continued SSE (Kalman filter) experiments. Performance is better than expected for hard registration events. Currently determining optimal state vector and error model.
- Designed applications for pulling relevant stereo pairs from DPPDB tapes. Finalizing preliminary design of reference image manager and stereo registration approach. SGI O2 workstations and disk drives for classified TSL lab due to arrive at the end of the month (*just* in time).
- Working with Sarnoff to establish Video Geolocation terrain, imagery, metadata, and registration metrics and models. Jointly preparing a briefing for AVS DARPA PM to present to the DARPA SPO Director. Continuing to leverage our valuable collaboration with UCF. Metrics is proving to be a very interesting research problem.
- Received written permission from DARPA PM to release AVS video and telemetry data to UCF. Delivered binary release of AVS baseline and 500 calibrated video frames from Oct. '99 Ft. A.P. Hill data sets for initial study.

June 2000:

- Hosted a productive on-site visit by the DARPA PM on 6/6/200. Decreased priority of imagery metrics in favor of getting DPPDB processing implemented ASAP.
- The AVS SI finally decided on MET® as the tool set they will use to drop points to measure registration performance on the program. Sent them a MET w/ DPPDB beta release under a restricted use, demonstration/evaluation only license. Built additional tools for working with DPPDB data.
- Nailed down the program-wide ICD for distributing video clips and evaluating registration performance, began implementing the ripple through our existing processes and code. Planned development of terrain/image/metadata/registration metrics and a predictive PVR performance model. Collaborating with Sarnoff on a briefing for the Director of the DARPA SPO planned for July.
- Arranged 7/6/2000 trip to General Atomics Aeronautical Systems for a technical interchange meeting concerning PVR value-added processing for the Predator UAV. Established contact with NIMA Motion Imagery Standards Board, planned to attend MISB meeting on 7/27 in Reston, VA. Downloaded all available docs from their website, focused on their Metadata specs which we'll try to influence to ensure our

ability to add value to the airborne video systems we'll be integrating with in the future. Supported five other video-related new business pursuits.

- Selected 10 clips for the July 17th performance evaluation, began pushing data through the processing pipeline. Progress has been hampered by: (1) AVS CM/data server down for 3 weeks due to HW failure; (2) excessive delays in getting our SGI O2 workstations for classified processing in the TSL (19 weeks from order submission until resources finally ready to use); (3) staffing transitions (training and resource re-allocation for 5 incoming, 2 outgoing video team members in the last 2 months); and (4) received 2 copies of half the Ft. Drum DPPDB instead of one copy of both halves.
- Arranging July meeting with Kalman filter experts outside of our immediate team from Harris GCSD and the Florida Institute of Technology to debate mathematical model issues and finalize our Sequential State Estimator design. Swirling on stereo registration and stereo-based point geolocation algorithms.
- Coordinated IR&D support to streamline video clip calibration processing via enhancements to Geopositioning and Accuracy Assessment tools within MET.

Accomplishments for the Quarter Ending September 30, 2000

PVR Development and Integration

July-August 2000:

- Visited General Atomics Aeronautical Systems on 7/6 for TIM on a PVR / Predator integrated demo. Lots of good info exchange with their systems engineers.
- Held AVS SSE Review on 7/12. Invited Prof. Fred Ham of FIT, J. Stiver of GCSD Palm Bay, and Garnett, McDowall, and Bell from the Harris DPL to get outsider suggestions and insight. Established an experimental close-out plan for our Kalman Filter work.
- PVR technology development highlights include:
  - Stood up initial DPPDB registration implementation.
  - Image Metrics computation designed (Entropy & Mutual Information).
  - Developed pre-screener algorithm to keep outliers out of Kalman filter.
  - Refined our Affine Consistent Subset algorithm.
  - Defined experiment-driven development path for Dynamic N-View Video to Stereo Reference Consistent Subset algorithms & architecture.
- Processed 6 stressing clips from Ft. Drum and Camp Lejeune data sets. Selecting additional Lejeune and Fallon NAS clips to process next. Coded applications compliant with program-wide ICD in preparation for 8/28 On-Site Evaluation of PVR Performance by NG-CMS.
- Participated in AVS Program Review on August 10-11.
  - Briefed Bob Hummel, the new DARPA PM, on our PVR development plan and presented our promising preliminary DPPDB performance results.
  - Will write whitepaper to secure our AVS GFY'01 funding of $1.2M for (1) analysis-based registration extensions, (2) technology transition activities (e.g., Predator demo), and (3) digital video architecture studies (MPEG-2, 480p, VISP metadata).

- Hummel invited the program team to submit "seedling" ideas that could be demonstrated this year and lead to follow-on programs.

- ♦ The NIMA Prototype Facility - Reston (NPF-R) has a new Video / Motion Imagery Office. They have a live Predator feed, an Onyx2 Infinite Reality, and lots of RAID disk space, suitable for a strong PVR technology transition demo.
- ♦ Delivered Quarterly Scientific & Technical Report and Quarterly Status & Management Report CDRLs. Shipped an updated MET w/ DPPDB release to NG-CMS.

September 2000:

- ♦ PVR technology development highlights include:

- Completed first-pass implementation of Stereo Consistent Subset, beginning testing on DPPDB data in the TSL classified processing facility.

- Began coding Mutual Information and Entropy metrics to quantitatively characterize PVR input imagery.

- Refined experiment-driven development path for Dynamic N-View Video to Stereo Reference Consistent Subset algorithms & architecture.

- ♦ Calibrated 4 Lejeune and 2 Fallon NAS clips. Having difficulty processing the mountain of data while simultaneously attempting new algorithm development.
- ♦ The AVS SI, NG-CMS, was a no-show for the scheduled 8/28 On-Site Evaluation of PVR Performance.
- ♦ Hosted an on-site AVS Program Review for Bob Hummel, the new DARPA PM, on 9/14. Gave him a complete history of AVS-PVR development, current status, and future plans, including in-depth technical details and lab demos. He has proposed that Harris take on the SI role for GFY'01 to ensure that the technology transition activities are successful, and the previously promised funding has been cut from $1.2M to $700K to focus on this task.

<u>Accomplishments for the Quarter Ending December 31, 2000</u>

PVR Development and Integration

October 2000:

- ♦ PVR technology development highlights include:

- Extracted DTED from DPPDB for Drum and Fallon sites in order to facilitate point transfer, as required by our new Stereo CSS algorithms. LeJeune and A.P. Hill DEM extractions are in work.

- Finished coding Mutual Information and Entropy metrics to quantitatively characterize PVR input imagery. Began using these algorithms to diagnose Stereo CSS behavior in the TSL.

- Began implementing Dynamic Video Worm registration algorithm to bridge scene content gaps and increase robustness.

- ♦ Pulled and began calibrating last 2 Fallon NAS and 4 A.P.Hill clips for PVR performance characterization using DPPDB. Received summer Ft. Drum data on 10/26 (the last data set we'll have to process). All clips will be processed and

performance results will be rolled up once the Stereo CSS problem is diagnosed and fixed (NLT 11/10).

- Reconfigured an AVS O2 workstation to support standalone demos of the AVS HMI in the field.
- Working on the SOW and schedule for the AVS GFY'02 ECP.
- Prepared & presented a PVR overview paper at the 29th AIPR Workshop. Submitted a research paper summary for the DCV'01 conference, where we hope to present the details of our Kalman filter study. We also plan to present a paper on our new Stereo CSS & Dynamic Video Worm registration algorithms at the Workshop on Video Registration to be held in conjunction with the International Conference on Computer Vision (ICCV2001) in July 2001.
- Delivered the Quarterly Scientific & Technical Report CDRL. This year's Computer Software Product End Item CDRL was delivered to NG-CMS in August.

November 2000:

- All staff has rolled off or greatly reduced hours until GFY'01 funding arrives.
- Dynamic Video Worm algorithm implementation and testing should be completed this month.
- Approximately 20 evaluation test clips will be ready for processing and analysis at the end of November.
- The revised SOW and high-level schedule for GFY'01 have been submitted for customer approval.

December 2000:

- All staff has rolled off until GFY'01 funding arrives.
- Supported an AVS Planning Meeting held at Sarnoff Corp. on Dec. 13th.
- First spiral of Dynamic Video Worm algorithm implementation was completed. Testing revealed a problem that could not be resolved before AVS funding ran out.
- 17 evaluation test clips are be ready for processing and analysis, but there is currently no program funding to run on the data.
- The RFP from CECOM arrived on December 20th, our response is due January 26th.

Accomplishments for the Quarter Ending March 31, 2001

PVR Transition and Validation

January 2001:

- All staff has rolled off until GFY'01 funding arrives.
- The GFY'01 SOW has been split into 2 parts (in-scope and out-of-scope with respect to the existing contract). We submitted our response to CECOM's RFP for the in-scope portion on 25 January. This should get us the first funding increment of $400K ASAP. We are expecting a second "out-of-scope" RFP for $300K to arrive in the next few weeks.
- Submitted our Quarterly Scientific & Technical Report CDRL.

February 2001:

- First increment of GFY'01 funding ($400K) arrived week of 2/19. Finalizing staffing plan, recalling team to kick off this year's work starting week of 3/5.
- The GFY'01 SOW has been split into 2 parts (in-scope and out-of-scope with respect to the existing contract). We submitted our response to CECOM's RFP for the out-of-scope portion on 22 February. This should get us the second funding increment of $300K "soon."

March 2001:

- Kicked off this year's work the week of 3/5. First set of tasks include getting the SW baseline back in order, documenting the existing system, up-front systems engineering for building the Predator model, and lead work for the validation tasks. Still waiting for word on the final increment of GFY'01 funding ($300K) so we can begin validation work.
- Sarnoff is having problems getting their Acadia HW PVR solution up and running, so we'll end up evaluating their current lab solution.

<u>Accomplishments for the Quarter Ending June 30, 2001</u>

PVR Transition and Validation

April-May 2001:

- Hosted an AVS Program Review at the Harris Melbourne, FL facility on May 1st.
- Preparing for a final AVS Demonstration in Arlington, VA, on July 31st. Re-planned the program to accommodate this activity (not in our 2 ECP's). Negotiating the possibility of obtaining loaner HW from SGI so we can put on the best possible demo of our PVR system for the government.
- Coordinating with Sarnoff on the Validation Task. They have been less than cooperative in helping us evaluate performance of both the Harris and Sarnoff PVR solutions.
- Established a good rapport with General Atomics, completed the up-front systems engineering work necessary to build Predator sensor models. Two models will be necessary to accommodate the various Predator configurations, one has been implemented and the second is almost complete. Beginning to build a telemetry decoder, will validate everything when we receive useful data.
- Attended JEFX'02 Industry Days, 31 May - 1 June; promoting our Video Time Critical Targeting whitepaper, supported by SMC, in support of tech transition.

June 2001:

- The Dynamic Video Worm registration algorithm developed under IR&D funding has proven to be a real winner during the AVS Validation against DOQ reference imagery. Our best clip had a mean of 3.0m and std. dev. of 1.3m with 100% of the frames yielding <10m post-registration error. 7 of 9 clips have better than 10m error for at least 90% of the frames, and the other two have significant scene content changes which spoil their results to 6-7m mean & 4m std dev, with ~80% frames

<10m error. The results we will be presenting at the IEEE Workshop on Video Registration are superior to those Sarnoff will be presenting at the main ICCV 2001 conference.

- After attending JEFX'02 Industry Day on 31 May & 1 June, we determined that our DARPA prototype is too far away from the mature product state required to meet all of the interoperability and security certification requirements of JEFX under their planned schedule (too many hoops and too many complicating factors, including simultaneous exercises for Millenium Challenge, joint US and NATO coalition participation, etc.). SMC (our sponsor) did not appear to be a major player, and there was not enough time to garner ASC and AC2ISR support for our PVP solution. However, we did learn a great deal about the current Time Critical Targeting toolset and Air Operations Center architecture, as well as identify good leads for other transition opportunities and high-priority customers to brief on our AVS successes.
- The 14 June briefing/TIM with NIMA MIPO was very productive. That customer enthusiastically supports us, stating "Harris has the right product at the right place at the right time to dovetail with our efforts." They want to evaluate our correlation algorithms for JTW, are hooking us up with GAVWG to discuss our Predator model and ideas for predictive error measures, and want us to participate in a NIMA AT study being conducted by Purdue to temper their analytical foundation with our real-world airborne video experience.
- The final AVS Capabilities Demonstration in Arlington, VA, has been postponed to August 30th. We have provided a Harris demo description to the SETA, and held a half-day TIM with SGI on 6/12 to negotiate a loaner 8 processor Origin 3000 series computer since the CAGS Onyx2 Infinite Reality will be unavailable/impractical.
- Sarnoff continues to stonewall the PVR Validation Task, shipping us useless data and avoiding any direct contact. We have defined the data formats and exchange protocols to mitigate their issues, and have shipped them the first two DOQ clips (Ft. Drum site). We'll ship the last 4 DOQ clips for LeJeune and APHill when they verify their ability to run on the first shipment, then we'll send our DPPDB clips for all four sites (including Fallon). Expanded Harris team to help calibrate our last 2 DOQ clips and clean up Sarnoff's calibration data. Examined NG-CMS survey data from last year, and found it practically worthless for absolute error characterization (would be lucky to evaluate a few reference images).
- Finished implementing our simple & rigorous Predator sensor models (2 models are necessary to accommodate the various Predator configurations). Arranging travel to General Atomics to obtain video and metadata from their archives that meet calibration and validation requirements. Predator ESD decoder HW has been procured, and have begun building the telemetry decoder software. Will validate our Predator PVR processing capability when we get good data.
- Prepared slides for our July 13th IEEE Video Registration Workshop invited talk, and started the customer & Harris approval to release processes.
- Prepared 3 orthomosaics & video clips for the Aug. 30th AVS Demo.

Accomplishments for the Quarter Ending September 30, 2001

PVR Transition and Validation

July 2001:

- Hosted on-site visit by NIMA-TO on July 3rd.
- Participated in the NIMA-sponsored Motion Imagery Geopositioning Workshop on 24-25 July to share our AVS experiences with the Purdue research team.
- Participated in a TIM with General Dynamics - Electronics Systems to help refine ideas for a whitepaper to NIMA-NTA to deliver video georegistration capability that would be complimentary to their MAAS (Multimedia Analysis & Archive System) product. We owe GD-ES a ROM on a loose integration of PVR and MAAS (new API's). Our proposal depends on the Predator sensor model validation funded by DARPA-AVS, and a port of PVR to Origin NT funded by this year's Motion Imagery IR&D.
- Briefing Harris PVR capabilities and AVS experience to the NIMA Precision Targeting Tiger Team on 31 July and to Navy PMA281 on 6 Sept. Arranging a briefing for NIMA-GIT (Geospatial Info Office, Transnational Center) ASAP.
- PVR Validation task progress: Harris DOQ runs and analysis are done. Harris DPPDB evaluation is in-work and should be complete by 8/3/01. Our outstanding results have been presented to DARPA and NIMA. Sarnoff has assigned Jim Matey to run their PVR system on our clips, and we are making good progress towards having Sarnoff validation against 6 DOQ clips completed in time for the August 30th AVS Demo. We'll try to have some limited Sarnoff DPPDB results by then as well.
- The final AVS Capabilities Demonstration in Arlington, VA, is set for August 30th. We have requested DARPA approval to deliver our AVS demo to SGI's Reality Center in Orlando when we return their equipment. The increased visibility should be beneficial to all concerned.
- Predator telemetry decoder software is 95% complete. We need to engineer a timestamp solution to get the data into our Telemetry Database. Predator sensor model validation has stalled while we negotiate General Atomics engineering support to help get our hands on useful data.

August 2001:

- Primary focus is the Final AVS Program Capabilities Demo on 8/30 and supporting DARPA/NIMA TIM on 8/29, trip report to follow next week. Obtained loaner Origin 3200 from SGI for demo. Validated Harris and Sarnoff PVR Systems using 6 DOQ clips, validated Harris PVR solution using 4 DPPDB clips (Sarnoff could not readily support DPPDB); results to be presented at 8/30 demo. Predator Sensor Model Validation stalled due to lack of data and GA-ASI cooperation.

September 2001:

- Supported DARPA/NIMA TIM on 8/29, successful AVS Program Capabilities Demo on 8/30. Obtained loaner Origin 3200 from SGI for demo. Showed autonomous PVR processing of streaming video data without interruption for over 30 minutes.

Potential end-users saw dynamically updating situational awareness and precision targeting displays, and our IR&D developed Georegistered Video Database (GVDB) demo. Performance Validation results were also presented (Harris PVR solution consistently out-performs Sarnoff at this time).

- Predator Sensor Model Validation stalled due to lack of data and GA-ASI cooperation. Upgrading spare GFE Norpak metadata decoder for Predator ground system compatibility.
- Sarnoff slow to resume work on validation analysis, we're helping them identify their problems and trying to accommodate their issues.
- Expect DARPA AVS program to extend beyond November 2001 due to NIMA support and continued interest in additional ACTD study efforts.

Accomplishments for the Quarter Ending November 30, 2001

PVR Transition and Validation

October 2001:

- Supported the NIMA Motion Imagery Geolocation Workshop at Wright-Patterson AFB 30 Oct - 1 Nov. Purdue presented their error modeling work needed for Smart Image, DARPA presented AVS, NIMA briefed plans for Smart Image and Precision Engagement programs, for which Harris has submitted ROMs. Important customer briefings included OSD UAV Roadmap 2000-2025, AFRL/SNAR geolocation programs for sensor fusion, and geolocation activities for the ASC/RAB Predator, PMA-263 VTUAV, and PEO IEW&S TUAV programs.
- Predator Sensor Model Validation stalled due to lack of data and GA-ASI cooperation, working other sources of data with NIMA. Metadata decoder hardware came back from the Norpak factory with upgraded firmware for Predator ground system compatibility.
- Sarnoff slow to resume work on validation analysis, we're helping them identify their problems and trying to accommodate their issues. On 10/23 we received results plots instead of the processed data required to do the analysis we're under contract to perform.
- There are discussions of another round of field demonstrations in December'01. Staffing is currently down to approximately 1.0 FTE.
- Requested no-cost program extension to the contract end date from 16 Nov 01 to 28 Feb 02.

November 2001:

- Provided an AVS-PVR capability abstract for a Lockheed Martin Mission Specific Technology Conference in support of USIGS-05.
- Provided a demo & briefing of Harris Motion Imagery capabilities and technology transition plans to JWAC at a TIM on 11/15/01.

- Provided our briefing materials & demo movies for video georegistration and RealSite technologies to the C2 Battlelab. Expect to be contacted regarding scope of a Jan'02 Video ISR initiative.
- Supported Harris responses to the Counter Terrorism BAA dated 10/25. Coordinated AVS Program inputs and wrote up a Quad Sheet submission for AVS Capabilities applied to Predator.
- Supported the NIMA Motion Imagery Geolocation Workshop at Wright-Patterson AFB 30 Oct - 1 Nov. Talked with Purdue Profs. Andrisani, Bethel, & Mikhail about our DCV'01 paper.
- Predator Sensor Model Validation stalled due to lack of useful data. Reviewed 16 hours of Predator video from GA-ASI and the UAV Battle Lab, working around problems as best we can. Finished the new software interface to the Predator metadata decoder hardware, following up changes rippling thru the PVR system. Have captured some clips for initial experimentation, but have requested better Baseline Predator GCS data from GA-ASI.
- In response to an invitation from UAV Battle Lab to bring PVR to the Predator View demonstration at Indian Springs, NV, we will participate in a DARPA-sponsored Predator UAV PVR Activity. We plan to get the best possible data from the ACTD GCS by observing and influencing Predator operations at the USAF Weapon School Mission Employment (ME) Exercise.
- Sarnoff finally provided new validation data on 11/27 (late), which we're analyzing for presentation at the 12/12/01 AVS Program Review in Annapolis, MD.
- AVS contract period of performance is now extended thru 2/28/02. Remaining work includes finishing the Predator model, completing our validation exercise, writing the final report, and closing out the program.

Accomplishments for the Quarter Ending February 28, 2002

PVR Transition and Validation

December 2001 – February 2002:

- Supported a Predator data collection exercise with the 11th RS training group at Indian Springs, NV, 4-7 Dec. 2001. Obtained good video data, but was not able to obtain suitable reference data to complete model calibration and PVR validation for operational UAV data before AVS program funding ran out.
- Supported the Final AVS Program Review at Annapolis, MD, 12-13 Dec. 2001.
- Wrote and submitted the PVR Validation Report (HLDD Update), Final Scientific and Technical Report, and Software Product End Item (AVS-PVR Release 11) CDRLs.